

HARVARD UNIVERSITY



LIBRARY

OF THE

Museum of Comparative Zoology

S-NA-San Diego

MUS. COMP. ZOOL.
LIBRARY

ATLAS OF
MONTHLY MEAN SEA SURFACE
AND SUBSURFACE TEMPERATURES
IN THE GULF OF CALIFORNIA, MEXICO

JUN 22 1973

HARVARD
UNIVERSITY

MARGARET K. ROBINSON

SAN DIEGO
SOCIETY OF NATURAL HISTORY

MEMOIR 5

1973

ATLAS OF
MONTHLY MEAN SEA SURFACE
AND SUBSURFACE TEMPERATURES
IN THE GULF OF CALIFORNIA, MEXICO

MARGARET K. ROBINSON

SCRIPPS INSTITUTION OF OCEANOGRAPHY

SAN DIEGO
SOCIETY OF NATURAL HISTORY

MEMOIR 5

1973

SAN DIEGO SOCIETY OF NATURAL HISTORY MEMOIRS

Memoir 5, pages 1-97
Issued April 16, 1973

PUBLISHED WITH FINANCIAL AID
FROM THE
W. W. WHITNEY PUBLICATIONS ENDOWMENT
AND BY DONATIONS FROM
THE AMERICAN FOUNDATION FOR OCEANOGRAPHY
SCRIPPS INSTITUTION OF OCEANOGRAPHY

INTRODUCTION

This atlas contains monthly mean sea temperature charts of the surface and four subsurface levels of the Gulf of California and the Pacific Ocean adjacent to the West Coast of Baja California, Mexico. The charts are presented in an expanded scale to show the complicated seasonal changes in sea temperature in the Gulf of California, and the great contrast between these temperatures and those on the Pacific side of Baja California.

Surface and subsurface climatic charts for the waters surrounding Baja California have great potential use for scientists, commercial and sport fishermen and tourists. Both sea surface and subsurface temperature charts are required to reveal the sharp temperature gradients associated with the thermocline, water mass boundaries, upwelling areas and the convergent region in mid Gulf, as well as the strong north-south and weak east-west temperature gradients across the Gulf, and the remarkable contrasts in the seasonal range of temperature on the two sides of Baja California. Detailed monthly temperature charts have heretofore been available only for the sea surface, and at a much reduced scale.

The abundance and location of marine life from the plankton and plankton-eaters to the carnivorous pelagic fish that migrate over vast oceanic areas, are affected by temperature and salinity. Salinity, however, is much less variable than temperature and, in general, is not the limiting factor controlling animal and plant populations.

The California Cooperative Oceanic Fisheries Investigations (1949-1970) were directed toward studies on the relationships of faunal abundance to environmental conditions along the Pacific Coast of Baja California (See CALCOFI Reports Vol. VII through XV, 1960-1971; CALCOFI Atlases Nos. 1 through 15, and bibliographies contained in volumes 1949 through 1960 of the Oceanic Operations of the Pacific, published by the University of California.) Additional papers of interest that concern the Pacific Coast region of Baja California, not included in the CALCOFI reports and atlases, are: Cromwell and Reid (1956), Hubbs and Roden (1964) and Tamayo

(1964). Of particular interest is CALCOFI Atlas No. 4 (Wyllie, 1966), which contains charts of geostrophic current flow at the surface and at 200 m. along the west coast of Baja California.

There have been few oceanographic investigations of the Gulf of California. Roden (1958, 1972) reviewed all studies of the physical oceanography of the Gulf. The first scientific cruise in the Gulf was made by the U. S. Fish Commission Steamer *Albatross*, in 1889 (Tanner, 1889), and this was followed by another cruise two years later (Townsend, 1901). Thorade (1909) published seasonal sea surface charts derived from ship logs, and Schott (1953) included a discussion of the Gulf of California in his monumental work on the Pacific Ocean.

Plankton collections from the 1921 expedition of the California Academy of Science to the Gulf were described by Allen (1923), and a general discussion of the expedition was given by Johnston (1924). Allen (1937) also described the plankton collected by the G. Allan Hancock Expedition to the Gulf in 1936, and he (1938) also worked up the data collected by the Templeton Crocker Expedition to the Gulf in 1935. Servicio Meteorologico Mexicano (1937, 1938) published climatic data on the Gulf region, including precipitation, evaporation, air temperature and wind.

In 1939 and 1940, H. U. Sverdrup led two expeditions of the *E. W. Scripps* to the Gulf of California. In addition to temperature and salinity hydrocast observations, these expeditions included observations of sedimentation, submarine topography, geology, paleontology and biology (see Revelle, 1950; Sverdrup, 1940, 1941, 1951; Sverdrup and staff, 1941; and Sverdrup, Johnson and Fleming, 1942). Gilbert and Allen (1943) discussed phytoplankton collections, Munk (1941) discussed the existence of internal waves in the Gulf, and E. R. Anderson (1953) discussed energy exchanges between ocean and atmosphere. Papers based on geological observations collected on the 1940 *E. W. Scripps* cruise were published in 1950, in Memoir 43 of the Geological Society of America.

Osorio-Tafall (1943, 1944, 1946) discussed

results of the Mexican expedition of the *M. N. Gracioso*. In 1956 and 1957, the CALCOFI program sponsored seven cruises into the Gulf. These data formed the basis for Roden and Grove's (1959) paper on the surface and deep circulation and water exchange across the mouth of the Gulf, upwelling, distribution of physical properties, and sea level. Papers published since 1964 have dealt primarily with conditions at the mouth of the Gulf, the region between Cabo Corrientes and the Revilla Gigedo Islas, and along the Pacific Coast.

Cromwell and Bennett (1959) published charts of surface drift currents, including the region south of 30° N, covered by this paper. Blackburn and associates (1962) discussed the oceanography of the Pacific Coast of Baja California and in the Gulf of Tehuantepec, in relation to tuna fisheries.

Van Andel and Shor (1964) edited a comprehensive collection of papers on the Marine Geology of the Gulf of California, based on observations made during the Vermillion Sea Expedition.

Griffiths (1963, 1965) published studies of ocean fronts off Cabo San Lucas, based on April-May 1960 observations, and he also published (1968) a report covering physical, chemical and biological oceanography of the entrance to the Gulf of California in 1960 and 1961.

Monthly charts of surface salinity covering the Eastern Pacific south of 30° N, based on CALCOFI data, were published by Bennett (1966). Wyrski (1966) summarized oceanographic conditions in the Eastern Pacific, south of 25° N, excluding the Gulf of California.

Stevenson (1970) reported on the physical and biological oceanography near the entrance of the Gulf of California, based on data collected on eight cruises during 1966-1967, that were a part of the EASTROPAC Expedition.

Warsh and Warsh (1971) studied the water exchange at the mouth of the Gulf of California, based on observations taken by the Vermillion Sea Expeditions (1959), the *Te Vega* Expedition (1967), and CALCOFI Cruise 5702. This paper was based on some of the data analysed by Roden and Groves (1959), but used different methods.

Roden (1972) discussed observations taken during the 1969 *Thomas G. Thompson* Expedition. This paper contained a detailed study of interchange of water across the mouth of the Gulf, based on STD (electronic salinity-tempera-

ture-depth sensor) observations.

The U. S. Department of Commerce publishes annual tide prediction tables for several locations along the Pacific Coast of Baja California and within the Gulf. The University of Arizona, in recent years, has published tidal curves for Puerto Penasco.

ACKNOWLEDGEMENTS

This work was supported by the Office of Naval Research, 1960-72; the National Science Foundation, 1961-65, and the U. S. Fleet Numerical Weather Central, 1965-72.

The following members of the BT Analysis and Processing Section of Scripps Institution of Oceanography have worked on the project: Marguerette Schultz, Viola Fleming and Edythe Drollinger.

The programming was done by Roger A. Bauer, C. Fremont Sprague, Marilyn McLennan and James N. Perdue.

The drafting was done by Leo Peters.

CHARTS

Figure 1 is a chart of geographic place names. The 72 horizontal charts that follow (Figs. 2-73) are arranged in 12 monthly groups, each containing 5 charts representing mean temperature at the surface, 100, 200, 300 and 400 ft., and a 6th chart showing the depth of the top of the thermocline. The charts are traced from computer plots made directly from the mean monthly temperatures for 1° quadrangles at the five selected levels generated by computer analysis programs. The contour interval is 1°F, based on means in tenths of Fahrenheit degrees. Contours end where the depth level of the chart intersects the bottom.

The top of the thermocline is defined as that depth at which the temperature is 2°F less than the surface temperature. This depth is found by linear interpolation between the mean temperatures at the 100 ft. levels. The thermocline topographies are contoured at 50 ft. intervals. If the temperature decreases less than 2°F in 400 ft. (the lowest analysis level), the thermocline is undefined. The 400 ft. depth contour is shown on all thermocline charts. Inside this contour, in winter, water is isothermal to the bottom. In summer, thermoclines develop in shallow shelf areas, as shown on the charts.

Figures 74-85 list numbers of observations by 1° quadrangles, by months, and Figure 86, the

1° quadrangle total for all months. These figures include both BT and reversing thermometer observations.

Additional charts (Figs. 87-88) present mean annual cycle curves for the 5 levels, in 1° quadrangles along the axis of the Gulf and at corresponding latitudes along the Pacific Coast of Baja California. These curves draw attention to marked seasonal temperature differences between the waters of the Gulf and adjacent Pacific Ocean. Figures 89-90 contain individual bathythermograph (BT) traces at two locations in the Gulf and two at corresponding latitudes along the Pacific Coast. These traces were selected to show typical temperature-depth structure at monthly intervals.

DATA

Data used in this temperature analysis came from several sources. The primary source was BT data on file at the Scripps Institution of Oceanography. Also included were reversing thermometer temperatures collected by the CALCOFI Program, published in the Oceanic Observations of the Pacific (1949-1960), and in CALCOFI Data Reports (1960-1966). The CALCOFI data cover both the Pacific Coast region west of Baja California and cruises into the Gulf of California. Table 1 lists ships and cruise dates of observations for the Gulf of California, north of 22°N. The time and space distribution of all observations is shown in Figures 74-86. The grand total of BT and reversing thermometer observations used in the temperature analysis was 35,804.

ANALYSIS PROCEDURE

The basic premise of the analysis system is, given an adequate sample, there would exist a smooth mean seasonal cycle curve in the temperature fields of the oceans that would vary with latitude, longitude and depth, depending upon the net effects of advection and on the local heat budget.

Computer programs have been developed to reduce the subjective hand analysis of data. The purpose of the programming effort was to produce a complete field of reasonable mean temperature values for each month and depth

Table 1. Collecting ships and cruise dates for BT data taken in the Gulf of California, north of 22°N.

SHIP	CRUISE DATE
<i>R/V ALEXANDER AGASSIZ</i>	IX 62; XI 63; V 65
<i>R/V ALASKA</i>	I and II 60; VII and VIII 61; II and III 62
<i>R/V SPENCER F BAIRD</i>	V 52; IX 56; II 57; IV, V and VI 59
<i>R/V BLACK DOUGLAS</i>	IX and X 52; II and IV 56; IV 57; I 60 and XII 62
<i>R/V CAYUSE</i>	III and IV 70
<i>USNS DAVIS</i>	X 67
<i>R/V DEFIANCE</i>	VI 67
<i>USS EDMONDS</i>	V 63
<i>USS GEORGE</i>	IX 55
<i>R/V HORIZON</i>	XII 56; III, IV and V 59; VI 64
<i>USS JASPER</i>	III 45
<i>USS LOWE</i>	IX 60
<i>R/V ORCA</i>	V 53
<i>USS PONTCHARTRAIN</i>	VI 68
<i>R/V PROTEUS</i>	VI, VII and VIII 69
<i>S. D. TUNA BOAT</i>	IV and VI 65
<i>R/V ELLEN B SCRIPPS</i>	V 68
<i>R/V E. W. SCRIPPS</i>	III 45
<i>R/V HUGH M SMITH</i>	IX 59; II and V 60; IV, X and XI 61
<i>R/V STRANGER</i>	V 56; VI and VII 57
<i>PLANE SUPERWIDGEON</i>	X 55
<i>R/V TE VEGA</i>	VII, VIII, IX, X and XI 67
<i>R/V VELERO IV</i>	III 49
<i>R/V THOMAS WASHINGTON</i>	I 68
<i>R/V WEST POINT</i>	III 61; VI 64
<i>R/V YELLOWFIN</i>	III and IV 52; I 55
<i>R/V YOLANDA</i>	X, XI and XII 66; I, II and IV 67

in the unit analysis grid, a 1° of latitude by 1° of longitude area. The analysis procedures were designed to permit subjective intervention and modification of the computer-produced numerical values whenever sparse data or lack of data produced unsatisfactory results.

Data Preparation.— Temperatures were read, tabulated and keypunched at 100 ft. levels, from individual BT prints. These data were combined with values at the same levels from standard level hydrocasts, interpolated when necessary. The data were ordered by 1° quadrangles by months, and monthly means and standard deviations were computed.

Main Analysis Programs.—The main computer analysis programs which have been developed and successfully used in open ocean areas consist of three steps based on input data of available 1° quadrangle means at selected analysis levels. The three computational steps consist of, 1) space interpolation, 2) space smoothing, and 3) time smoothing. The first two steps do not produce satisfactory results in narrow seas, such as the Gulf of California, the Red Sea and the Adriatic, or in cases where space coverage is inadequate in some months. In these areas, a combination of subjective methods and computer programs must be used. The programs as described were used, except north of 22°N in the Gulf.

1. Interpolation:

The space interpolation phase of the program solves the set of simultaneous two-dimensional linear interpolation equations:

$$T_{i,j} = (T_{i-1,j} + T_{i+1,j} + T_{i,j-1} + T_{i,j+1})/4$$

Within the $T_{i,j}$ array, values may be observed, missing or excluded (land). The equations are only solved if the value $T_{i,j}$ is missing, leaving the observed values unaltered. The equations are solved using an iterative method (Peaceman and Rachford, 1953). This procedure does not produce satisfactory results when the iterative process fails to converge due to inadequate data in some months in the Gulf; e.g., January, July, September, October, November and December.

2. Space smoothing:

The space smoothing process replaces each value, either observed or interpolated, by the values determined by a least squares fit to a straight line of the three points centered, where possible, at the point being smoothed. The process is carried through, first, along latitudes and then, along longitudes. This simple technique has proved especially effective in reducing extreme values found in the raw data field.

The space-smoothing program was omitted in the final results because the geographic configuration of the Gulf of California prevented production of satisfactory results.

3. Time smoothing:

After interpolating and space smoothing, there are 12 separate fields for each level, representing the mid-point of each month. The 12 monthly values for each depth-latitude-longitude are used as input to a fourier function:

$$F(m) = a_0 + \sum_{k=1}^3 \left[a_k \cos \left(\frac{k m \pi}{6} \right) + b_k \sin \left(\frac{k m \pi}{6} \right) \right]$$

where $F(m)$ represents the smoothed monthly temperature, and a_i and b_i are the fourier coefficients defined by the formulas:

$$a_k = 1/6 \sum_{m=1}^{12} T_m \cos \left(\frac{11k(m-1)}{6} \right), \quad b_k = 1/6 \sum_{m=1}^{12} T_m \sin \left(\frac{11k(m-1)}{6} \right)$$

The fourier function is solved by summing over the first three harmonics and the values obtained for each month fall on smoother time curves than the input values, since a 6th harmonic sum would be required to pass through every input value.

Both 3rd and 6th harmonic curves were produced from the Gulf of California values.

Testing Vertical Consistency.—The analysis program operates on each level independently and may produce values that are not vertically consistent. The three processes that can cause vertical inconsistency are: 1) interpolation over different distances at various levels; 2) space smoothing to different degrees at separate levels, and 3) time smoothing at locations where the true subsurface annual cycle curve has a cusp or pointed peak shape that a 3rd harmonic curve cannot produce. Values in each 1° quadrangle are checked by computer graphic techniques and subjective editing to ensure that vertical inconsistencies are removed.

Special Handling of Gulf of California Data.—Available 1° quadrangle monthly means were computer-plotted by levels against time on transparent vellum, and smooth curves were drawn between the plotted points. Linear interpolation was used, primarily during period of rapid increase or decrease of temperature in spring or fall; curvilinear interpolation in mid-winter and mid-summer, times of minimum and maximum temperatures. Means were altered if they appeared to be typical of early or late month, rather than mid-month time. Subsurface time curves were constructed similarly, with particular attention paid to maintaining isothermal relationships with depth in months where they occur.

During the curve drawing, if data were missing in more than one month in a given quadrangle, comparisons were made with curves of adjacent quadrangles for shape guides. When all curves were drawn, mid-month temperature values were read from the curves and listed

geographically by months and levels. These values were contoured. Whenever any value appeared to be out of space context with surrounding values, the original curves were re-examined for possible shape changes that might improve the space context. These requirements, simply stated, meant that a missing month's value had to fall between those of adjacent months, but at such a point that the north-south or east-west temperature gradients were maintained.

The data along the east coast of the Gulf are fewer than along the Baja California coast. In constructing curves in these coastal areas, especial efforts were made to insure that the time interpolations maintained reasonable horizontal gradients with adjacent 1° quadrangles. The thermocline intersects some depth levels between spring and fall. The raw data means near the thermocline may fluctuate widely from month to month. Rather than smoothing subjectively, in these cases, all sets of data were run through the 3rd harmonic program, which modifies smooth curves only slightly but suppresses shorter period oscillations. This program frequently produces vertical inconsistency in the fall months. A further program compares the vertical gradients of the input and output data of the 3rd harmonic program. If an increase of temperature with depth occurs in the output (the cusp problem) but not in the input, the output value is altered to maintain the original gradient. Only in cases where both sets of data show positive gradients are such allowed to remain in the final results.

From such corrected data, 6th harmonic annual cycle curves are produced (Figs. 87-88). The monthly values shown on these curves are the same as those contoured in Figures 2-73. A comparison of the horizontal temperature charts and the annual cycle curves with the distribution of observations in Figures 74-86, will indicate where the subjective interpolations were made.

DISCUSSION

Oceanographic conditions represented by distributions of temperature and salinity differ widely in the Gulf of California from the situation along the west coast of Baja California. The causes of the differences are mainly geographic. The Gulf of California is a long, narrow, trough-shaped basin, with depths greater than 1,500

fms. at the mouth of the Gulf, 23°N . It's center length is approximately 600 miles, and it's width ranges from 60 miles near Isla Tiburon to 110 miles at 23°N .

The Gulf is divided into a deep southern trough, and a shallow northern section, where the continental shelf — with depths less than 100 fms. — covers more than 60% of the area. The narrow basins — Sal si Puedes and Delfin — lie between the Angel de la Guarda and San Lorenzo Islas and the coast of Baja California, and are connected at 300 fms. These basins reach depths greater than 830 fms. and 400 fms., respectively, but both are isolated from deeper water to the south by sill depths of 230 fms. The narrow passageway between San Esteban (=San Sebastian) and San Lorenzo Islas has depths slightly greater than 300 fms., but these waters are also cut off from the Tiburon basin, whose sill depth is 230 fms., and maximum depth, 400 fms. North of Islas Tiburon, San Esteban and San Lorenzo, 90% of the area has depths less than 200 fms., and the three deep basins have sills between 230-240 fms. South of these islands in the central trough, depths quickly descend to 1,200 fms., then more gradually until depths of 1,800 fms. are reached at 23°N . However, the deeper areas are in reality a series of closed basins. Table 2, reproduced from van Andel (1964) lists basin and sill depths.

The continental shelf is narrow on the Baja California side. There are numerous small indentations, coves and headlands along the coast, and south of 26°N , many islands jut up from the shelf. Along the Mexican coast, between $27-24^\circ\text{N}$, there are many low lying elongated bar islands, beyond which lie tropical lagoons.

Because of the Gulf topography, the oceanographic distributions will be affected as follows:

Table 2. Basins of the Gulf of California.

Basin	Maximum Depth (fms.)	Sill Depth (fms.)
Sal si Puedes, and Delfin	830	240
Tiburon	400	230
San Pedro Martir	540	450
Guaymas	1,090	850
Carmen	1,480	930
Farallon	1,760	1,020
Pescadero	2,030	1,340
Mazatlan	1,700	1,580

There are three regimes — 1) the shallow water north of the islands; 2) the deep basins, Sal si Puedes, Delfin, and Tiburon, and 3) the region south of the islands.

In the first, there is a very large annual range of temperature at the surface, small at 400 ft., because of the smaller volume of water to be heated and cooled. Tidal ranges will be large because of pile up of water on the shallow shelf. Spring tide ranges at Cabo Tepoca, $30^{\circ}16'N$, $112^{\circ}52'W$, are 13 ft., and are 23 ft. at the Colorado River entrance, $31^{\circ}46'N$, $114^{\circ}44'W$.

Tidal currents will be large in the Ballenas Channel, between Isla Angel de la Guarda and Baja California, and in the narrow passage between Islas San Lorenzo and San Esteban, and tidal mixing produces low temperatures in these areas. In the northern basins, temperature and salinities will retain sill depth values to the bottom. For example, the temperature at 800m. in the Sal si Puedes Basin is $52.3^{\circ}F$ ($11.34^{\circ}C$), while mean temperatures at this depth in the southern trough are near $41.9^{\circ}F$ ($5.5^{\circ}C$).

In the southern region, other factors play a large part, particularly in the case of upwelling, where the shape of the coastline, as well as direction and speed of the winds, are important. The direction of the winds and the atmospheric circulation are largely determined by the axis of the Gulf and its relation to the chain of mountains that run the entire length of Baja California, and the more distant but high Sierra Madre Occidental mountain range. These mountain ranges form a channel through which the wind blows from NW, in winter, and from SE, in summer. These winds and their changes of direction produce upwelling in the lee of headlands and islands on both sides of the Gulf.

The wind-driven circulation is responsible, too, for the exchange of water into and out of the Gulf. Under NW winds, the flow at the surface is out of the Gulf, with compensating flow into the Gulf at depth, and with SE winds, there is flow into the Gulf at the surface and out, at depth. The exchange of water through the mouth of the Gulf, also, is related to the fact that evaporation exceeds precipitation and run-off at all times in the northern basin, along the coast of Baja California, and, November through May, along the east coast. Heavy rainfall falls in summer along the Mexican coast from Topolobampo to Cabo Corrientes, but this rainfall does not materially affect the distribu-

tion of salinity in the Gulf, nor the overall excess of evaporation which requires a net inflow of ocean water at the mouth of the Gulf.

South of Islas Tiburon and Angel de la Guarda, tides are diurnal and range from 2.4 ft. at Santa Rosalia, to 3.9 ft. at Bahia Concepcion. (U. S. Department of Commerce Tide Tables.)

Along the Pacific coast of Baja California, the continental shelf is narrow except inside of Isla Cedros in Bahia Sebastian Vizcaino, and between Punta Abreojos and Cabo San Lazaro. There are numerous small crescent coves, in addition to the major headlands of Punta Eugenia and Cabo San Lazaro. The California current south of $30^{\circ}N$ becomes a wide slow drift, but the water that flows south is colder than at similar mid-ocean latitudes, and these differences are enhanced by coastal upwelling which occurs during the periods of prevailing NW winds. Wyllie (CALCOFI Atlas Series No. 4, 1966) gives details of the California Current during the period 1949-1965. In only March, April and May does the near-shore current flow southeast the entire length of the Baja California coast. In other months, the main current moves offshore and a series of eddies develop on the inshore side, bringing flow toward the coast, or northward along the coast, depending upon the size and location of the eddies.

The major eddy development is south, or southwest of Punta Eugenia, but other cells develop west and southwest of Cabo San Lazaro. In September and January, there is a third smaller eddy which develops farther north, west of the Cabo Colnett and Cabo San Quintin region ($31^{\circ}N$). At 200m., there is northwest flow along the coast in January and April, from Cabo San Lucas to Punta Eugenia; in February, May, and June, north from Punta Baja ($30^{\circ}N$); in July, August, and September, almost the entire length of the coast, and in October, November, and December, intermittent north flow in offshore eddies. North of $25^{\circ}N$, most winds are from the NW or NNW throughout the year, and most intense upwelling occurs north of Punta Eugenia. South of $25^{\circ}N$, the winds shift to N and NNE, away from the coast, colder water is found offshore and the north flow along shore has higher temperatures. NE winds are most frequent in August and November through February. Except during frontal passages, no southerly winds blow along the coast. During periods when strong NNE winds blow offshore,

there are light winds along shore south of Punta Eugenia, and it is during this period that the northward flow along shore is best developed (EASTROPAC Atlas, 1972; Forrest Miller, pers. comm.).

Between Cabo San Lucas, the Revilla Gigedo Islas and Cabo Corrientes, there is a convergence zone where three water masses meet — California current low temperature, low salinity water, north flowing equatorial water with higher temperatures and intermediate salinities, and Gulf of California water with high temperatures and high salinities. This region is marked by sharp temperature and salinity gradients at the surface, and subsurface temperature and salinity inversions (Cromwell and Reid, 1956; Griffith, 1963, 1965; Stevenson, 1970; Warsh and Warsh, 1971; Roden, 1972).

Along the west coast of Baja California, mean tide ranges are from 3.8 ft. at Bahia Magdalena, to 5.9 ft. at Isla Cedros; spring tide ranges at these locations are 5.3 and 7.5 ft., respectively.

The differences in temperature regimes between the Gulf of California and the Pacific coast of Baja California, between 23-30°N, are summarized in Table 3, which lists latitude maxima, minima and ranges of temperature by months for the five depths at which the mean temperatures have been analyzed. The table also includes the differences between the two latitude ranges.

At the surface and 100 ft., the Pacific latitude ranges are much larger than in the Gulf, May through November — maximum Pacific range, 23.1°F; maximum Gulf range, 14.8°F. In other months the differences are small, with Gulf ranges slightly larger, December through April, at the surface, but only in December at 100 ft. At 200, 300 and 400 ft., the differences vary from .2°F to 8.6°F, with Gulf ranges larger July through October. The maximum and minimum temperatures are not always at the same places, particularly below 200 ft., and reference should be made to the horizontal temperature charts for precise locations. A comparison of the absolute values of temperatures in these tables indicate the greatest difference between the regions is in the values of maximum temperatures at the surface and 100 ft.

At the surface there is a wider range of salinity along the Pacific side of Baja California than in the Gulf (Table 4). Along the Pacific Coast, mean salinities increase from 33.51‰ at 31°N,

to 34.49‰ at 23°N. In the Gulf, salinities decrease from a maximum of 35.58‰ at 31°N, to 34.93‰ at 23°N. At 125m. (410 ft.), the differences are not so great, but Pacific salinities increase with depth and Gulf salinities decrease. The 23°N values are typical of these two water types as they approach the convergence zone.

The major features in the isotherm fields, which can be seen in Figures 2-73, are:

1. Gulf of California

- a. In the narrow gulf, the pattern of the surface isotherms is quite variable. Among the more stable features is the cold water in the Ballenas Channel, due to turbulent mixing of tidal currents. There are tight gradients at the head of the deep trough, and November-May, tight gradients at the mouth of the Gulf. When the gradients are tight the trend of isotherms is usually perpendicular to the Gulf. October-June, temperatures at the mouth are higher than at the head of the Gulf. In August and September, temperatures reach a high of 87°F at the head of the Gulf, but also are found just beyond the mouth, near Mazatlan. There is no clearcut sequence of change from warmer water on one side to the other of the Gulf.
- b. At 100 ft., December through May, isotherms run mostly east-west south of 28°N, but near Ballenas Channel and Isla Angel de la Guarda, the trend changes and becomes parallel to the coast. Beginning in June and extending through September, the isotherms run parallel to the Gulf over most of its length, with warmer water on the Mexican Coast. The warm cell centered at 24°N, is associated with pile-up and downwelling of warm surface water, and deepening of the thermocline, while on the Baja California Coast upwelling occurs. This situation is consistent with the occurrence of prevailing SE winds at this time. This condition lasts through September. October is a month of change and the opposite situation develops in the southern area, with higher temperatures on the Baja California Coast and low temperatures and upwelling on the Mexican Coast. This reversal, which takes place with the shift to northerly winds, lasts until April. May is also a month of change.
- c. The location of the upwelling area can best

be identified on the 200, 300 and 400 ft. charts by pockets of minimum temperatures. The charts show that upwelling is

better developed and extends over a greater distance (23-28°N) along the Mexican Coast than off the Baja California Coast.

Table 3. Latitude ranges of temperature for the Gulf of California and along the Pacific Coast of Baja California. (All temperatures in °F.)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Surface												
Pacific:												
Max.	69.5	67.8	68.1	69.3	70.6	72.4	76.0	80.7	83.7	82.8	78.5	73.3
Min.	55.9	56.1	56.7	56.5	65.1	57.3	59.2	63.4	62.4	61.8	61.2	58.6
Range	13.6	11.7	11.4	12.8	15.5	15.1	16.8	17.3	21.3	21.0	17.3	14.7
Gulf:												
Max.	71.8	71.0	72.5	74.6	77.2	81.5	84.8	87.8	87.8	86.5	82.8	77.5
Min.	58.5	57.2	57.7	60.4	65.2	71.2	78.2	82.9	82.6	75.8	69.9	60.8
Range	13.3	13.8	14.8	14.2	12.0	10.3	6.6	4.9	5.2	10.7	12.9	16.7
100 ft.												
Pacific:												
Max.	69.2	66.4	66.1	67.1	67.0	66.4	68.0	72.5	77.0	78.4	76.7	73.2
Min.	55.7	53.9	52.4	51.1	50.5	51.6	53.5	54.5	54.6	55.3	56.6	56.9
Range	13.5	12.5	13.7	16.0	16.5	14.8	14.5	18.0	22.4	23.1	20.1	16.3
Gulf:												
Max.	70.4	69.1	68.5	69.2	71.5	80.0	83.7	86.2	87.6	83.1	79.2	77.5
Min.	57.7	57.2	57.7	59.8	63.5	68.3	73.6	75.6	76.6	75.2	69.0	60.0
Range	12.7	11.9	10.8	9.4	8.0	11.7	10.1	10.6	11.0	7.9	10.2	17.5
200 ft.												
Pacific:												
Max.	66.0	63.6	62.1	62.0	61.2	60.2	61.6	64.7	66.2	65.5	65.6	66.7
Min.	52.7	52.2	51.5	50.2	49.3	49.3	50.5	51.1	51.9	53.0	53.7	53.4
Range	13.3	11.4	10.6	11.8	11.9	10.9	11.1	13.6	14.3	12.5	12.1	13.3
Gulf:												
Max.	65.3	63.8	63.2	62.8	64.0	68.9	77.0	85.2	85.0	80.4	72.3	65.9
Min.	57.6	57.1	57.7	58.5	60.7	61.4	64.3	64.8	65.5	65.4	62.2	58.6
Range	7.7	6.7	5.5	4.3	3.3	7.5	12.7	10.4	19.5	15.0	10.1	7.3
300 ft.												
Pacific:												
Max.	60.9	59.4	59.2	58.2	58.2	57.8	58.8	60.9	61.3	59.8	59.3	60.5
Min.	51.2	50.8	50.3	49.6	49.0	48.8	49.3	50.3	51.1	50.6	50.6	51.5
Range	9.7	8.6	8.9	8.6	9.2	9.0	9.5	10.6	10.2	9.2	8.7	9.0
Gulf:												
Max.	61.7	61.4	59.4	60.0	61.7	67.7	72.2	76.2	75.2	70.6	65.2	62.2
Min.	56.1	55.7	56.6	56.2	57.5	58.5	60.4	59.6	56.6	56.0	56.0	56.1
Range	5.6	5.7	2.8	3.8	4.2	9.2	11.8	16.6	18.6	14.6	9.2	6.1
400 ft.												
Pacific:												
Max.	57.7	56.5	55.6	55.9	56.2	56.0	56.9	58.5	58.4	57.3	56.2	57.4
Min.	49.7	49.6	49.2	48.9	48.6	48.3	48.9	49.8	49.9	49.3	49.0	49.4
Range	8.0	6.9	6.4	7.0	7.6	7.7	8.0	8.7	8.5	8.0	7.2	8.0
Gulf:												
Max.	58.8	58.7	58.8	59.5	60.6	62.4	64.0	66.2	65.2	63.2	60.5	59.3
Min.	53.4	53.0	53.6	54.0	56.1	56.1	56.4	57.0	54.2	54.2	54.5	54.3
Range	5.4	5.7	5.2	5.5	4.5	6.3	7.6	9.2	11.0	9.0	6.0	5.4
Pacific range minus Gulf range:												
Surface	.3	-2.1	-3.4	-1.4	3.5	4.8	10.2	12.4	16.1	10.3	4.4	-2.0
100 ft.	.8	.6	2.9	7.6	8.5	3.1	4.4	7.4	11.4	4.2	9.9	-1.2
200 ft.	5.6	4.7	5.1	7.5	8.6	3.4	-1.6	3.2	-5.2	-2.5	2.0	6.0
300 ft.	4.1	2.9	6.1	4.8	5.0	.2	-2.6	-6.0	-8.4	-5.4	.5	2.9
400 ft.	2.6	1.2	1.2	1.5	3.1	1.4	.4	-.5	-3.5	1.0	.8	3.0

where it extends from Punta Arena to Bahia Concepcion. It is also interesting to note that the pockets of minimum temperatures along the Baja California Coast almost disappear from the 400 ft. charts, and that even during periods, June-September, when upwelling occurs on the Baja Coast, there is a cold spot at 24°N on the Mexican Coast.

2. Pacific Coast

- a. At the surface there is a change in direction in the slope of the isotherms from SE to E to NE, proceeding south, heading into shore. The shift varies from month to month.
- b. At 100 ft., the shift in direction from E to NE does not occur, January-June. Beginning in April and extending through October, as the seasonal thermocline develops, there is a marked increase in the temperature gradient perpendicular to the coast. August through October, there is a sharp increase in the north-south gradient between Punta Abreojos and Cabo San Lazaro. Minimum temperatures, indicative of upwelling, lie along shore from 29-31°N, with centers in the lee of Punta Baja, Punta Banda, and in some months, of Punta Abreojos.
- c. At 200 ft., the patterns are similar to those at 100 ft. but temperatures are lower. The cold tongue south of Punta Eugenia in September, October, and November, is better developed and extends farther south. Northward flow is indicated along the coast south of Punta Abreojos.
- d. At 300 ft., February through June, the shift in trend of isotherms from SE to E is less pronounced. Offshore gradients have decreased from those in the levels above.

July through January, south of 25°N, the cold tongue is well developed and northward flow is indicated from Cabo San Lucas to Cabo Magdalena.

- e. At 400 ft., both north-south and east-west temperature gradients have decreased. The cold tongue south of Punta Eugenia is broader and less pronounced than at 200 and 300 ft. It appears in July and extends through February. The higher on-shore temperatures indicate northward flow along shore between Cabo San Lucas and Cabo San Lazaro. In the other months, the shift in direction of isotherms from SE to E is less pronounced, with only a slight indication of a shift to NE.
- f. The thermocline charts which present only the topography of the top of the seasonal thermocline, indicate the direction of the surface flow, which is parallel to the isolines, with direction such that the slope of the discontinuity surface is down to the right when facing downstream. The subsurface countercurrent along shore is not indicated by the topographies of the top of the seasonal thermocline.

Figures 87-88 contain plots of annual cycle curves along the axis of the Gulf and at corresponding latitudes along the Pacific coast of Baja California. These charts add a fourth dimension, time, to the presentation of temperature data. They also draw attention to the marked seasonal temperature differences between the annual cycles in the waters of the Gulf and along the Pacific coast of Baja California, and from north to south in the two areas. Differences between areas are not so great in winter, but are very large in summer, when the gulf waters show a

Table 4. Average salinities in Gulf of California and along Pacific coast of Baja California.

POSITION	SALINITY ‰		POSITION	SALINITY ‰	
	Surface	410'		Surface	410'
31°N, 116°W	33.51	33.92	31°N, 113°W	35.58	*
30°N, 116°W	33.51	33.84	30°N, 113°W	35.43	34.95
29°N, 115°W	33.57	33.89	29°N, 113°W	35.39	*
28°N, 115°W	33.61	34.02	28°N, 112°W	35.14	35.00
27°N, 115°W	33.65	*	27°N, 111°W	35.32	34.98
26°N, 114°W	33.90	34.11	26°N, 110°W	35.29	34.90
25°N, 113°W	34.05	34.30	25°N, 110°W	35.26	34.94
24°N, 112°W	34.05	34.45	24°N, 109°W	35.11	34.83
23°N, 111°W	34.49	34.53	23°N, 108°W	34.95	34.79

*Depths do not extend to this level.

Table 5. Positions, dates and collecting ships for observations shown on Figures 89-90.

89 A.		POSITION	DATE	SHIP
		25°46.8'N, 110°46'W	I-23-68	<i>R/V THOMAS WASHINGTON</i>
		25°45.8'N, 110°54'W	II-15-57	<i>R/V SPENCER F BAIRD</i>
		25°07'30"N, 110°25'W	III-14-59	<i>R/V HORIZON</i>
		25°05.5'N, 110°45.5'W	IV-22-56	<i>R/V BLACK DOUGLAS</i>
		25°38'N, 110°14'W	V-24-65	<i>R/V ALEXANDER AGASSIZ</i>
		25°36'N, 110°52'W	VI-12-57	<i>R/V STRANGER</i>
		25°02'N, 110°32'W	VI-23-57	<i>R/V STRANGER</i>
		25°29'N, 110°15'W	VIII-13-57	<i>R/V STRANGER</i>
		25°06'N, 110°13'W	IX-29-67	<i>R/V TE VEGA</i>
		25°24'N, 110°57'W	X- 3-52	<i>R/V BLACK DOUGLAS</i>
		25°17'N, 110°28'W	XI- 6-67	<i>R/V TE VEGA</i>
		25°55.5'N, 110°58'W	XII-12-56	<i>R/V HORIZON</i>
89 B.		POSITION	DATE	SHIP
		25°24'N, 113°43'W	I-12-68	<i>USNS CHARLES H DAVIS</i>
		25°54'N, 113°07'W	II-22-51	<i>R/V CREST</i>
		25°34'30"N, 113°45'30"W	III- 8-52	<i>R/V CREST</i>
		25°02'36"N, 113°23'24"W	IV- 7-53	<i>R/V SPENCER F BAIRD</i>
		25°34'N, 113°47'W	V- 8-56	<i>R/V STRANGER</i>
		25°11'N, 113°04'W	VI-11-57	<i>R/V HORIZON</i>
		25°00'N, 113°23'W	VII-22-52	<i>R/V PAOLINA T</i>
		25°55'N, 113°56'W	VIII-27-56	<i>ITTC MARY LOU</i>
		25°47'N, 113°32'W	IX-11-56	<i>ITTC MARY LOU</i>
		25°05'N, 113°10'W	X-25-54	<i>HMCS LABRADOR</i>
		25°57'N, 113°21'W	XI-14-65	<i>S. D. TUNA BOAT</i>
		25°54'N, 113°25'W	XII-29-64	<i>S. D. TUNA BOAT</i>
90 A.		POSITION	DATE	SHIP
		28°26'N, 112°46'W	I-29-60	<i>R/V ALASKA</i>
		28°00'N, 112°11.5'W	II-13-56	<i>R/V BLACK DOUGLAS</i>
		28°30'N, 112°45'W	III-29-70	<i>R/V CAYUSE</i>
		28°10'N, 112°00'W	IV- 1-70	<i>R/V CAYUSE</i>
		28°37.5'N, 112°56'W	V-16-65	<i>R/V ALEXANDER AGASSIZ</i>
		28°00'N, 112°11'W	VI-16-57	<i>R/V STRANGER</i>
		28°07'N, 112°22'W	VII-28-67	<i>R/V TE VEGA</i>
		28°39'N, 112°25'W	VIII-17-57	<i>R/V STRANGER</i>
		28°27'N, 112°49'W	VIII-21-57	<i>R/V STRANGER</i>
		28°14'N, 112°28'W	X- 9-67	<i>R/V TE VEGA</i>
		28°37.5'N, 112°56.3'W	XI-24-63	<i>R/V ALEXANDER AGASSIZ</i>
		28°20.5'N, 112°13.5'W	XII-13-56	<i>R/V HORIZON</i>
90 B.		POSITION	DATE	SHIP
		28°16'N, 115°47'W	I-11-68	<i>USNS CHARLES H DAVIS</i>
		28°19'30"N, 115°55'W	II-11-54	<i>R/V HORIZON</i>
		28°27'N, 115°35'W	III-14-52	<i>R/V CREST</i>
		28°24'N, 115°45'30"W	IV-13-52	<i>R/V BLACK DOUGLAS</i>
		28°28'N, 115°35.5'W	V-14-56	<i>R/V STRANGER</i>
		28°28'N, 115°36'W	VI-13-54	<i>R/V CREST</i>
		28°18'N, 115°55'12"W	VII-21-57	<i>R/V BLACK DOUGLAS</i>
		28°55'N, 115°27.5'W	VIII-17-56	<i>R/V BLACK DOUGLAS</i>
		28°28'N, 115°55'W	IX- 1-57	<i>USS PRESTIGE</i>
		28°34'N, 115°53'W	X-16-67	<i>USNS DAVIS</i>
		28°12'N, 115°45'W	XI- 6-67	<i>USNS DAVIS</i>
		28°58'N, 115°48'W	XII-20-56	<i>R/V HORIZON</i>

rapid increase of temperature in spring and similar decrease in fall. Differences become less, proceeding south, until at 23°N the annual cycles are similar.

Figures 89-90 present copies of BT traces at two locations in the Gulf (25 and 28°N), and two at corresponding latitudes along the Pacific Coast. These traces were selected to show typical temperature-depth structure at monthly intervals. Table 5 lists the positions, dates and collecting ships for the observations duplicated in these drawings. Some traces extend below 400 ft., the deepest level for which we have prepared monthly charts. The traces show development of a shallow seasonal thermocline in summer, followed by deepening of the isothermal layer, as the surface layer cools in the fall. There are similarities in the monthly changes of temperature-depth structure at the four localities, although there are marked differences in the absolute temperatures. There are subsurface temperature inversions, which do not show in the average charts because the temperature increase is less than the contour interval, the vertical extent less than the selected analysis levels, or the occurrence is intermittent and, thus, lost in the averaging process.

SUMMARY

The monthly horizontal temperature charts and annual cycle curves contained in this atlas provide for the first time a comprehensive space-time description of the mean temperature distribution, surface to 400 ft., for the waters of the Gulf of California and the Pacific coast of Baja California. Because upwelling replenishes the euphotic zone, these waters are highly productive areas that have not as yet been fully utilized. It is hoped these charts, which more fully describe the oceanography of the area, will be useful in the further development and utilization of fish populations — the economic bonus at the top of the ocean's food chain.

BIBLIOGRAPHY

- Allen, W. E.
1923. Observations on surface distribution of marine diatoms of lower California in 1921. (XXIII): Expedition of the
- C. A. S. to the Gulf of California in 1921). California Acad. Sci. Proc., ser. 4, 12(23): 437-442.
1937. Plankton diatoms of the Gulf of California obtained by the G. Allan Hancock Expedition of 1936. Hancock Exped. 3(4): 47-59.
1938. The Templeton Crocker Expedition to the Gulf of California in 1935, the phytoplankton. Trans. Amer. Micros. Soc. LVII(4): 328-335.
- Allison, E. C.
1964. Geology of areas bordering Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 3-29.
- Anderson, C. A.
1950. 1940 *E. W. Scripps* cruise to the Gulf of California. Part I: Geology of the islands and neighboring land areas. Geol. Soc. Amer., Mem. 43.
- Anderson, E. R.
1953. The exchange of energy between a body of water and the atmosphere with application in evaporation. Scripps Inst. Oceanogr., Univ. California, dissertation.
- Bennett, E. B.
1966. Monthly charts of surface salinity in the Eastern Tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 11(1): 3-44.
- Benson, R. N.
1964. Preliminary report on radiolaria in recent sediments of Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 398-400.
- Biehler, S., R. L. Kovach, and C. R. Allen
1964. Geophysical framework of northern end of Gulf of California structural province. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 126-143.
- Blackburn, M., and associates
1962. Tuna oceanography in the Eastern Tropical Pacific. U. S. Natl. Mar. Fish. Svc., Spec. Sci. Rept. Fish, 400, IV. 48 pp.
- California Cooperative Oceanic Fisheries Investi-

gations Atlas Series:

Data Collection and Processing Group, Marine Life Research Program, Scripps Institution of Oceanography, La Jolla, California.

1. 1963, Anonymous. CALCOFI atlas of 10-meter temperatures and salinities, 1949 through 1959.
2. 1964, Fleminger, A. Distributional atlas of calanoid copepods in the California Current region, Part I.
3. 1965, Alvarino, A. Distributional atlas of chaetognatha in the California Current region.
4. 1966, Wyllie, J. G. Geostrophic flow of the California Current at the surface and at 200 meters.
5. 1957, Brinton, E. Distributional atlas of euphausiacea (Crustacea) in the California Current region, Part I.
6. 1967, McGowan, J. A. Distributional atlas of pelagic molluscs in the California Current region.
7. 1967, Fleminger, A. Distributional atlas of calanoid copepods in California Current region, Part II.
8. 1967, Berner, L. Distributional atlas of thaliacea in the California Current region.
9. 1968, Kramer, D., and E. H. Ahlstrom. Distributional atlas of fish larvae in the California Current region: Northern anchovy, *Engraulis mordax* (Girard), 1951 through 1965.
10. 1969, Isaacs, J. D., A. Fleminger, and J. K. Miller. Distributional atlas of zooplankton biomass in the California Current region: Spring and Fall, 1955-1959.
11. 1969, Ahlstrom, E. H. Distributional atlas of fish larvae in the California Current region: Jack mackerel, *Trachurus symmetricus*, and Pacific hake, *Merluccius productus*, 1951 through 1966.
12. 1970, Kramer, D. Distributional atlas of fish eggs and larvae in the California Current region: Pacific sardine, *Sardinops caerulea*

(Girard), 1951 through 1966.

13. 1971, Smith, P. E. Distributional atlas of zooplankton volume in the California Current region, 1951 through 1966.
14. 1969, Isaacs, J. D., A. Fleminger, and J. K. Miller. Distributional atlas of zooplankton biomass in the California Current region: Winter, 1955-1959.
15. 1971, Wyllie, J. G., and R. J. Lynn. Distribution of temperature and salinity at 10 meters, 1960-1969, and mean temperature, salinity and oxygen at 150 meters, 1950-1968, in the California Current.

California Cooperative Oceanic Fisheries Investigations Reports:

State Fisheries Laboratory, California Department of Fish and Game, Marine Research Committee, Long Beach, California. Volumes: VII, January 1960; VIII, January 1961; IX, January 1963; X, January 1965; XI, January 1967; XII, May 1968; XIII, January 1969; XIV, September 1970; XV, September 1971.

Calvert, S. E.

1964. Factors affecting distribution of laminated diatomaceous sediments in the Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 311-330.

Cromwell, T., and E. B. Bennett

1959. Surface drift charts for the Eastern Tropical Pacific Ocean. (In English and Spanish.) Inter-Amer. Trop. Tuna Comm., Bull. 3(5): 215-237.

Cromwell, T., and J. L. Reid, Jr.

1956. A study of ocean fronts. Tellus 8(1): 94-101.

Curry, J. R., and D. G. Moore

1964. Pleistocene deltaic progradation of Continental Terrace, Costa de Nayarit, Mexico. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 193-215.

Durham, J. W.

1950. 1940 *E. W. Scripps* cruise to the

- Gulf of California. Part II: Megascopic paleontology and marine stratigraphy. Geol. Soc. Amer., Mem. 43: 1-216.
- Gilbert, J. Y., and W. E. Allen
1943. The phytoplankton of the Gulf of California obtained by the *E. W. Scripps* in 1939 and 1940. J. Mar. Res. 5: 89-110.
- Griffiths, R. C.
1963. Studies of oceanic fronts in the mouth of the Gulf of California, an area of tuna migrations. F. A. O. Fish Rept. 6(3): 1583-1609.
1965. A study of the ocean fronts off Cape San Lucas. U. S. Natl. Mar. Fish. Svc., Spec. Sci. Rept., Fish, 499. 54 pp.
1968. Physical, chemical, and biological oceanography of the entrance to the Gulf of California. U. S. Natl. Mar. Fish. Svc., Spec. Sci. Rept. 573: 1-47.
- Harrison, J. C., and S. P. Mathur
1964. Gravity anomalies in Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 76-89.
- Hilde, T. W. C.
1964. Magnetic profiles across Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, 3: 122-125.
- Hubbs, C. L., and G. I. Roden
1964. Oceanography and marine life along the Pacific Coast of Middle America, pp. 143-186. In, Handbook of Middle American Indians, 1. University of Texas Press, Austin.
- Johnston, I. M.
1924. Expedition of the California Academy of Sciences to the Gulf in 1921. California Acad. Sci. Proc. 12: 951-1218.
- Munk, W. H.
1941. Internal waves in the Gulf of California. J. Mar. Res. 4: 81-91.
- Natland, M. L.
1950. 1940 *E. W. Scripps* cruise to the Gulf of California. Part IV: Report on Pleistocene and Pliocene foraminifera. Geol. Soc. Amer., Mem. 43: 1-55.
- Osorio-Tafall, B. F.
1943. E. Mar de Cortes y la productividad fitoplanctonica de sus aguas. Escuela Nac. Cienc. Biol. Anales 3: 78-118.
1944. Los estudios hidrobiologicos en Mexico y la conveniencia de impulsarlos. Rev. Soc. Mexicana Hist. Nat. 5: 127-153.
1946. Contribucion al conocimiento del Mar de Cortes. Soc. Mexicana de Geografia y Estadistica, Bull. 62: 89-139.
- Parker, R. H.
1964. Zoogeography and ecology of macro-invertebrates, Gulf of California and Continental Slope of Western Mexico. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 331-376.
- Peaceman, D. W., and H. H. Rachford
1953. The numerical solution of parabolic and elliptic differential equations. J. Soc. Ind. Appl. Math. 3: 28-41.
- Phillips, R. P.
1964. Seismic refraction studies in Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 90-121.
- Phleger, F. B.
1964. Patterns of living benthonic foraminifera. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 377-394.
- Revelle, R.
1950. 1940 *E. W. Scripps* cruise to the Gulf of California. Part V: Sedimentation and oceanography. Geol. Soc. Amer., Mem. 43: 1-6.
- Roden, G. I.
1958. Oceanographic and meteorological aspects of the Gulf of California. Pacific Sci. XII(1): 21-45.
1963. Shallow temperature inversions in the Pacific Ocean. J. Geophys. Res. 69(14): 2899-2914.
1964. Oceanographic aspects of Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa,

- Mem. 3: 30-58.
1970. Aspects of the Mid-Pacific transition zone. *J. Geophys. Res.* 75(6): 1097-1109.
1972. Thermohaline structure and baroclinic flow across the Gulf of California entrance and in the Revilla Gigedo Islands region. *J. Phys. Oceanogr.* 2(2): 177-183.
- Roden, G. L., and G. W. Groves
1959. Recent oceanographic investigations in the Gulf of California. *J. Mar. Res.* 18(1): 10-35.
- Rusnak, G. A., and R. L. Fisher
1964. Structural history and evolution of Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 144-156.
- Rusnak, G. A., R. L. Fisher, and F. P. Shepard
1964. Bathymetry and faults of Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 59-75.
- Schott, G.
1935. *Geographie des Indischen und Stillen Ozeans*. Hamburg, C. Boysen Verlag, 413 pp.
- Shepard, F. P.
1950. 1940 *E. W. Scripps* cruise to the Gulf of California. Part III: Submarine topography of the Gulf of California. *Geol. Soc. Amer., Mem.* 43: 1-32.
1964. Sea floor valleys of Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 157-192.
- Stevenson, M. R.
1970. On the physical and biological oceanography near the entrance of the Gulf of California, October 1966-August 1967. *Inter-Amer. Trop. Tuna Comm., Bull.* 14: 389-504.
- Sverdrup, H. U.
1940. The Gulf of California. *Assoc. Ocean. Phys., Proc. Verb.* 3: 170-171.
1941. The Gulf of California: Preliminary discussion of the cruise of the *E. W. Scripps* in February and March 1939. 6th Pac. Sci. Cong. Proc. 3: 161-166.
1951. Evaporation from the oceans, compendium of meteorology. Amer. Meteor. Soc., pp. 1071-1081.
- Sverdrup, H. U., M. W. Johnson, and R. H. Fleming
1942. *The Oceans*. Prentice Hall, Inc., New York, 1087 pp.
- Sverdrup, H. U., and staff
1941. Research within physical oceanography and submarine geology at the Scripps Institution of Oceanography during April 1940 to April 1941. Amer. Geophys. Union, Trans. 21: 490-494.
- Swain, F. M., P. L. Miller, and E. C. Mandelbaum
1964. Ostracoda from Gulf of California. Marine Geology of the Gulf of California, a symposium. Amer. Assoc. Petrol. Geol., Tulsa, Mem. 3: 395-397.
- Tamayo, J. L.
1964. Hydrography of Middle America, pp. 84-121. In, *Handbook of Middle American Indians*, 1. University of Texas Press, Austin.
- Tanner, F. L.
1889. Report on investigations of the U. S. Fish Commission Steamer *Albatross* for the year ending June 20, 1889. U. S. Fish Comm. Rept. for 1888, pp. 395-512.
- Thorade, H.
1909. Über die Kalifornische Meeresströmung. *Hydro. U. Marit. Met., Ann.* 37: 17-34, 63-76.
- Townsend, C. H.
1901. Dredging and other records of the U. S. Fish Commission Steamer *Albatross*, with bibliography relative to the work of the vessel. U. S. Fish Comm. Rept. for 1900, pp. 387-562.
- U. S. Department of Commerce
1969-1972. Tide Tables: West Coast North and South America. (Issued annually.) National Ocean Survey, National Oceanic and Atmospheric Administration, Rockville, Md.
1972. Eastropac Atlas. National Marine Fisheries Service Circular 330, Vol. 1, June 1972. National Oceanic and Atmospheric Administration, Rockville, Md.
- U. S. Hydrographic Office
1947. Atlas of the surface currents: North-

- eastern Pacific Ocean. Pub. 570.
University of Arizona
1967-71. Tide calendars for Puerto Penasco.
(Issued annually.) Dept. of Bio. Sci.,
University of Arizona, Tucson.
- University of California
1957-1965. Oceanic observations of the
Pacific — 1 volume each for data in
the following periods: pre-1949;
1949; 1950; 1951; 1952; 1953; 1954;
1955-NORPAC; 1955; 1956; 1957;
1958, and 1959. Scripps Institution
of Oceanography, University of Cali-
fornia.
- Van Andel, T. H.
1964. Recent marine sediments of Gulf of
California. Marine Geology of the
Gulf of California, a symposium.
Amer. Assoc. Petrol. Geol., Tulsa,
Mem. 3: 216-310.
- Van Andel, T. H., and G. G. Shore
1964. Preface. Marine Geology of the Gulf
of California, a symposium. Amer.
Assoc. Petrol. Geol., Tulsa, Mem. 3
- Warsh, C. E., and K. L. Warsh
1971. Water exchange at the mouth of the
Gulf of California. J. Geophys. Res.
76(33): 8098-8106.
- Wyrski, K.
1966. Oceanography of the Eastern Equa-
torial Pacific Ocean. Oceanogr. Mar.
Biol., Ann. Rev. 4: 33-68.

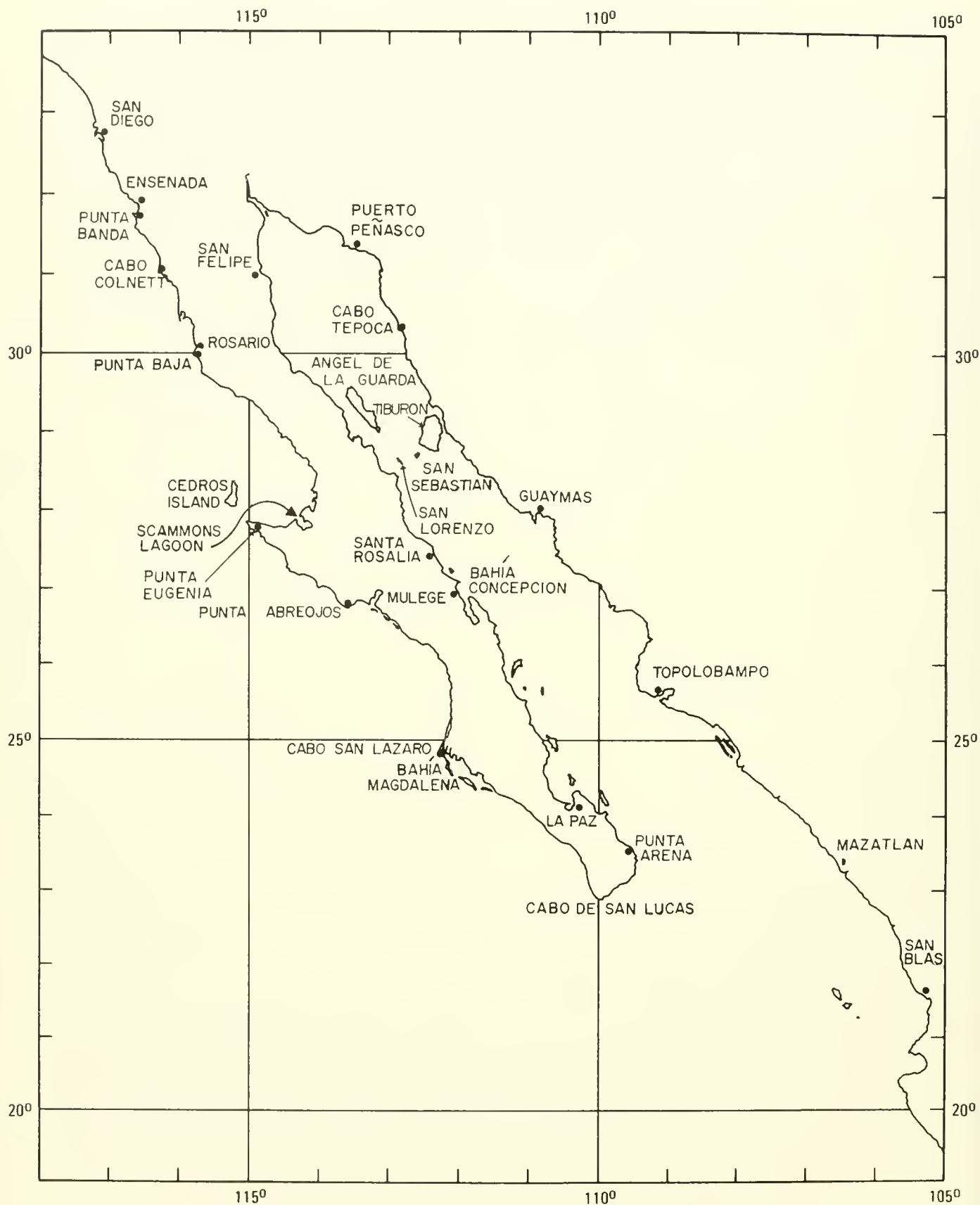


Figure 1. Geographic place names.

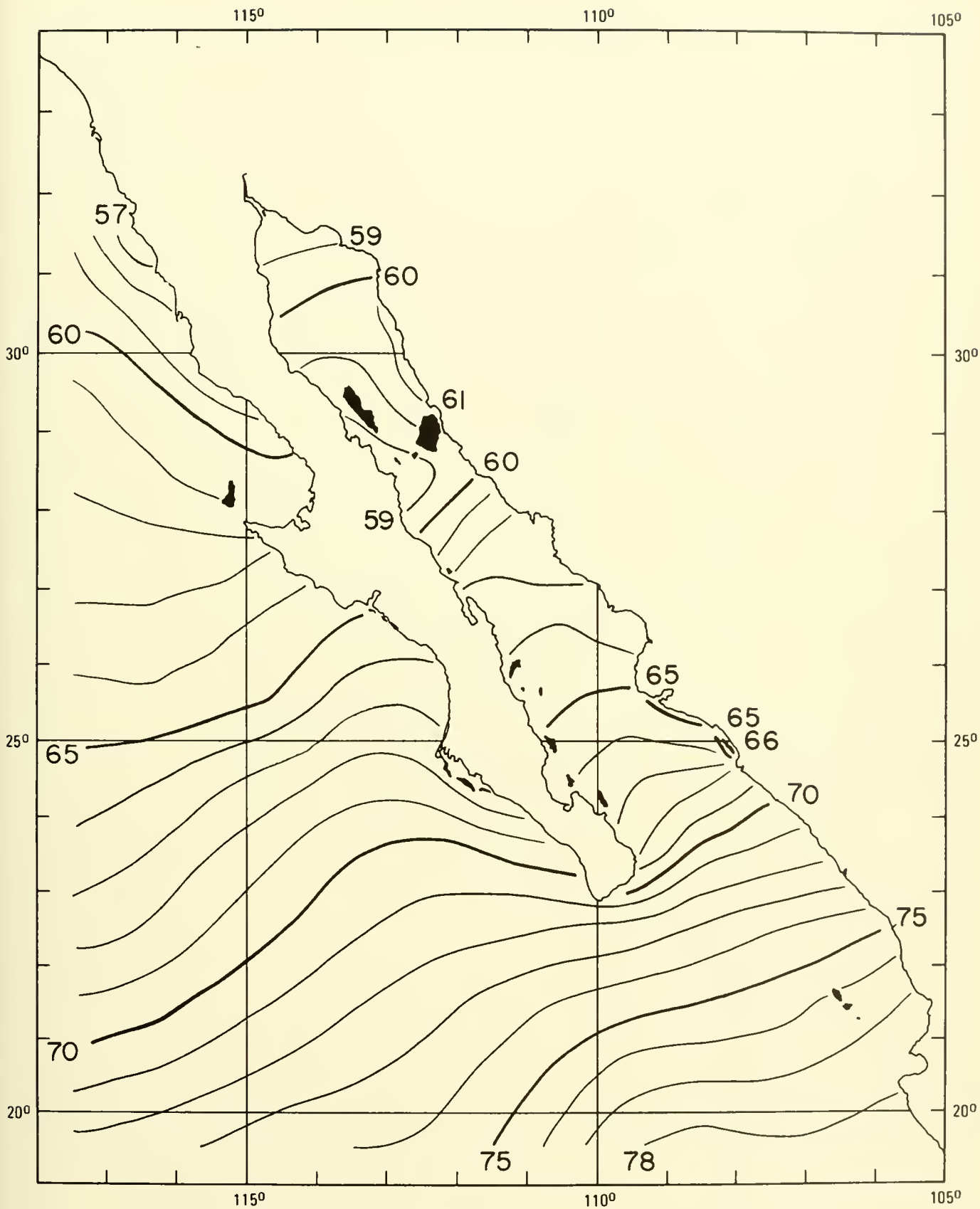


Figure 2. January mean sea surface temperatures (°F).

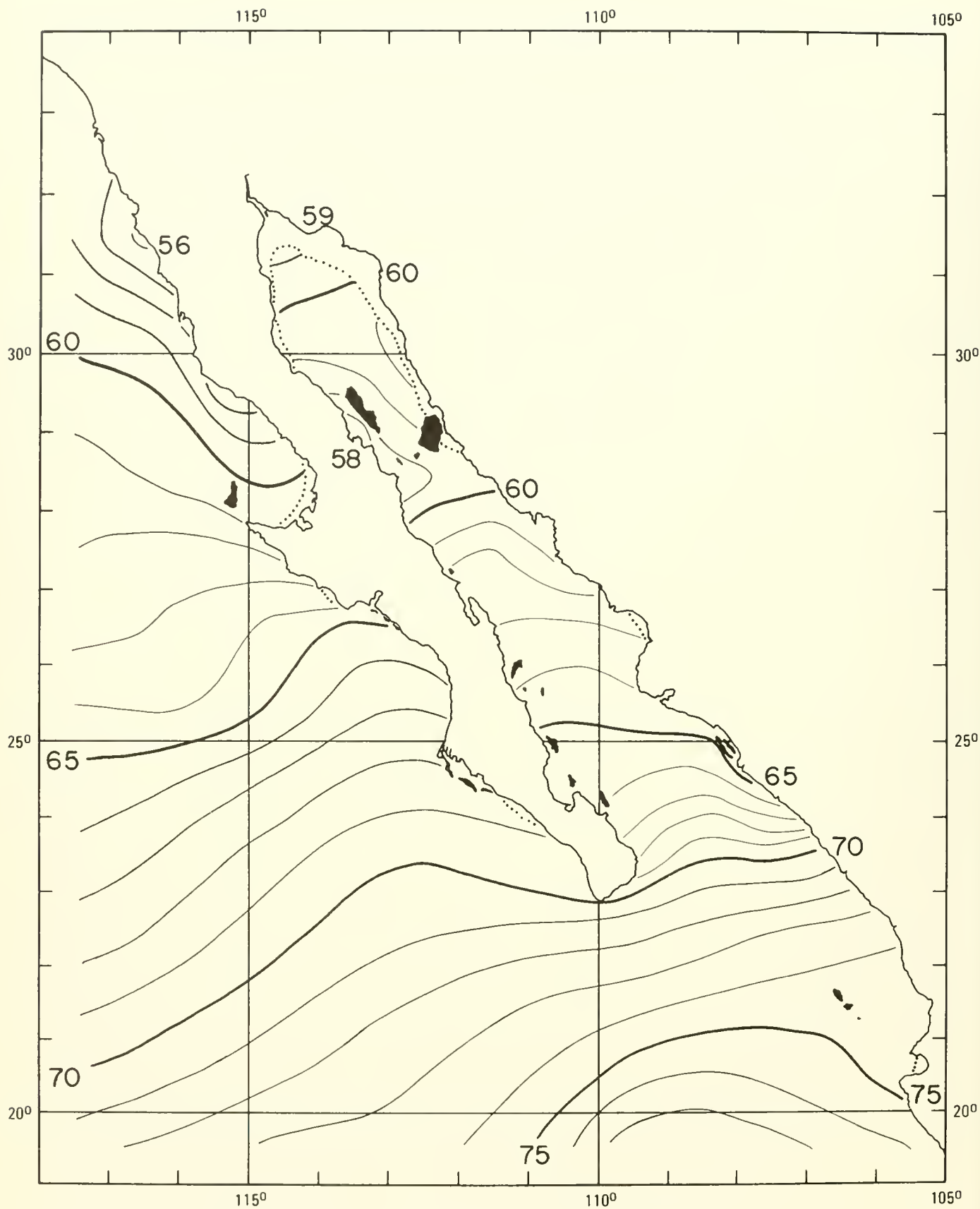


Figure 3. January mean temperatures ($^{\circ}$ F) at 100 feet.

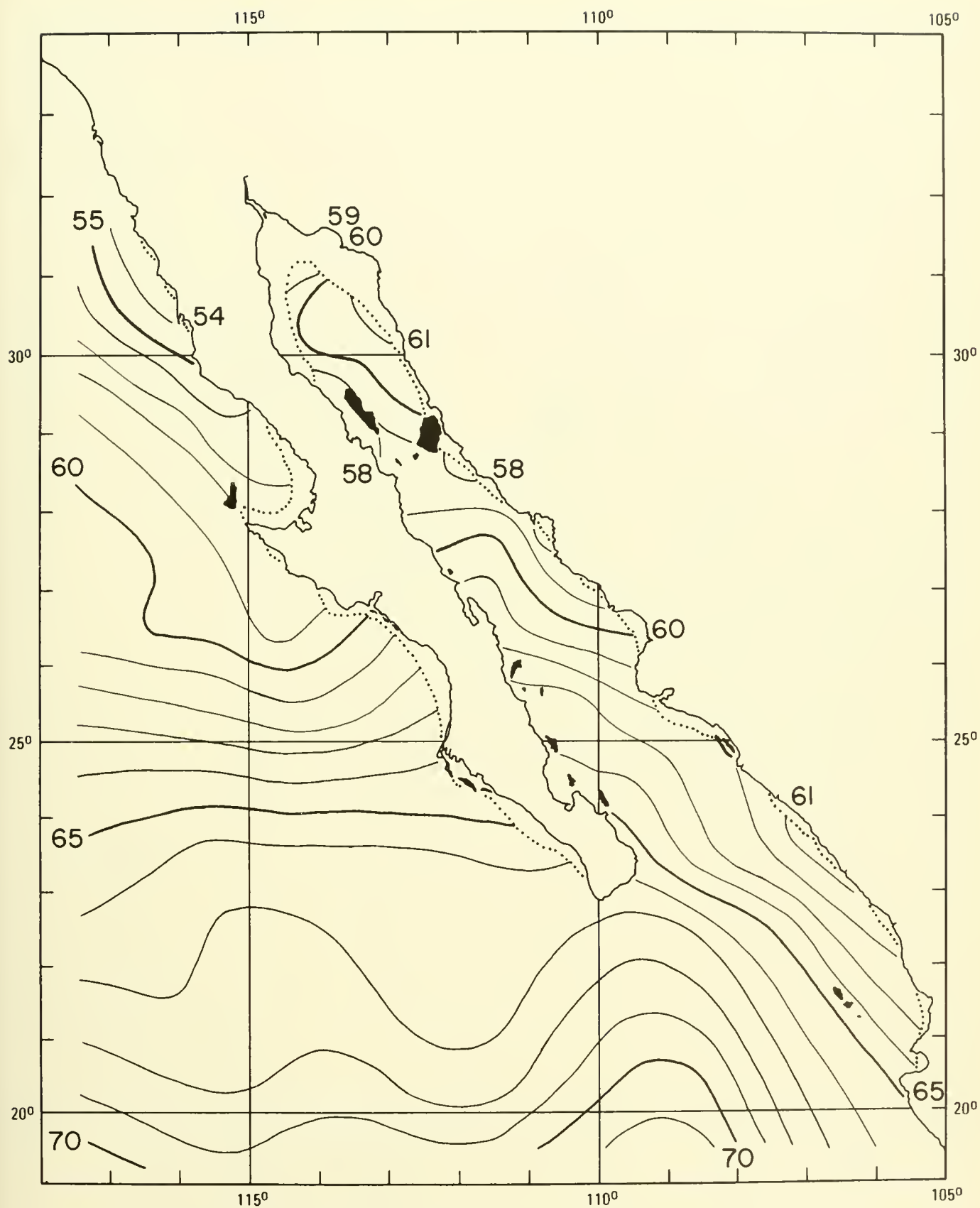


Figure 4. January mean temperatures ($^{\circ}$ F) at 200 feet.

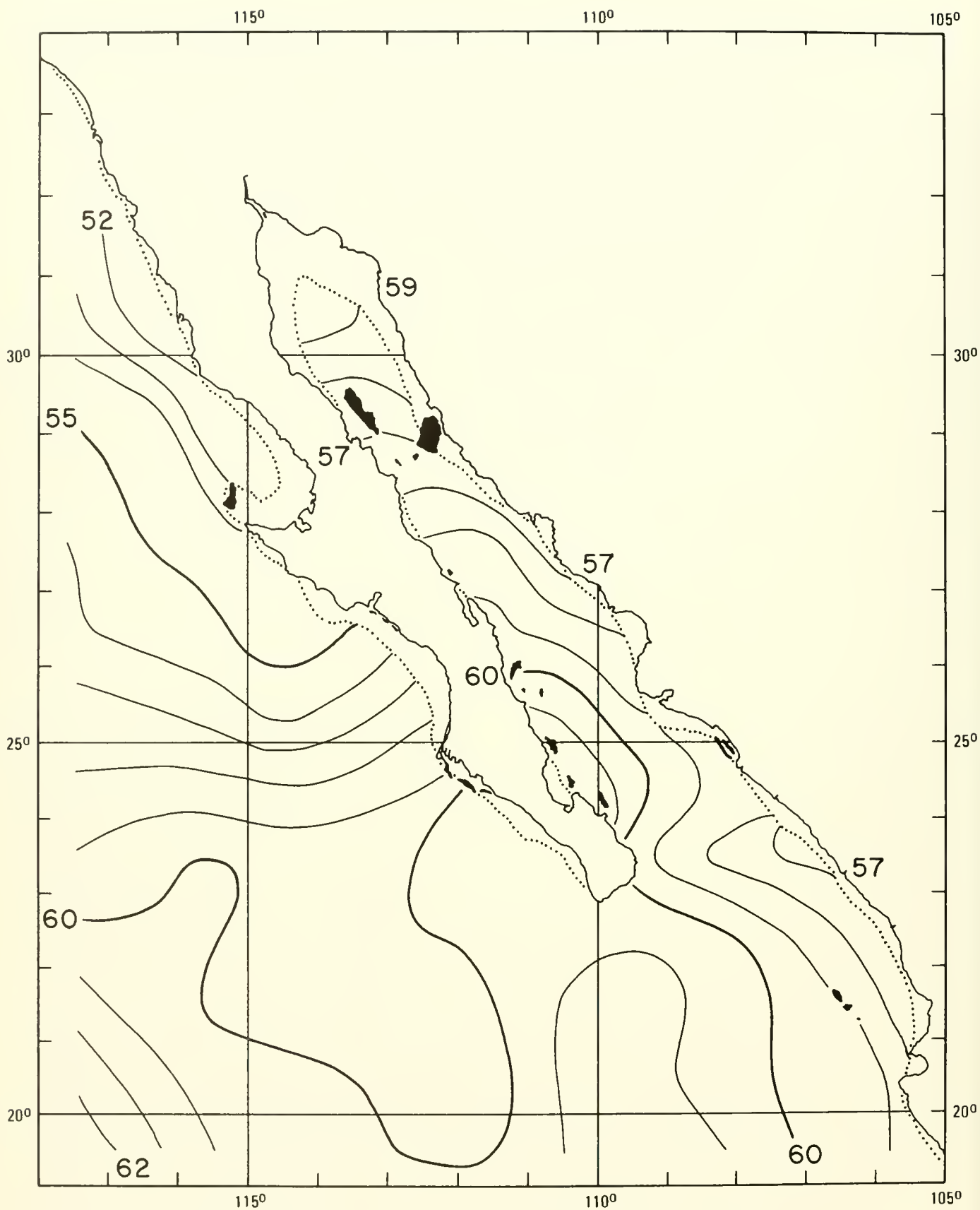


Figure 5. January mean temperatures ($^{\circ}$ F) at 300 feet.

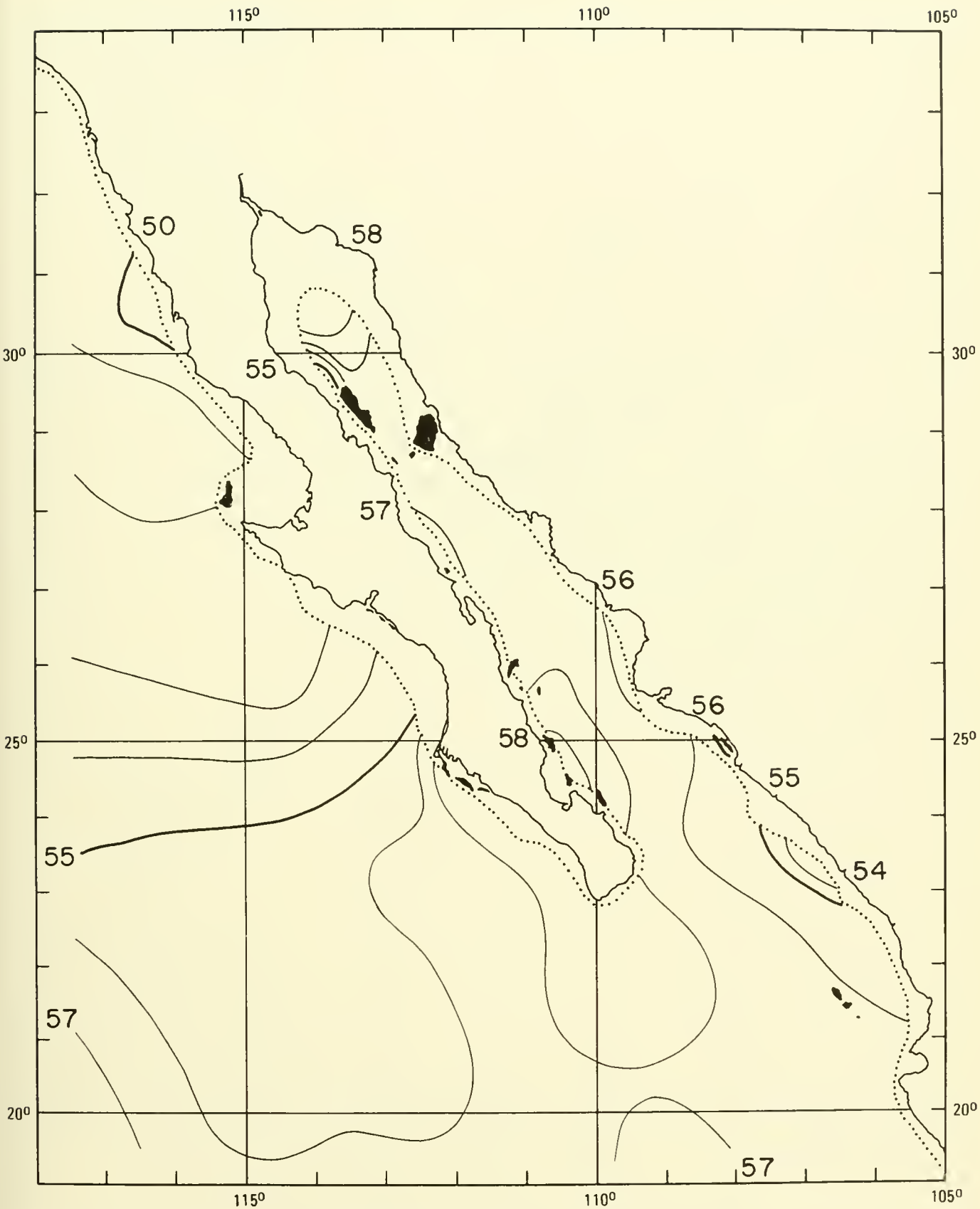


Figure 6. January mean temperatures ($^{\circ}$ F) at 400 feet.

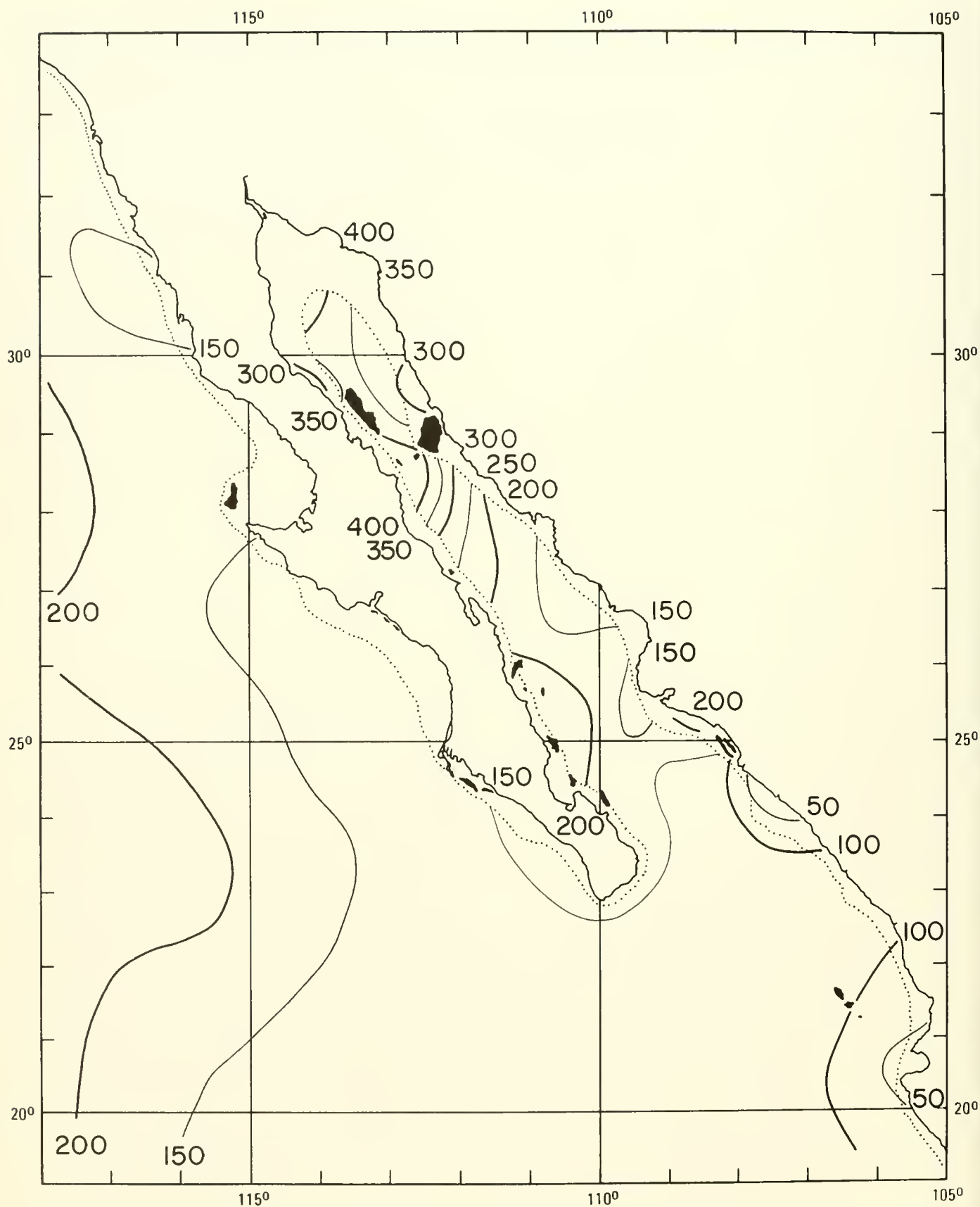


Figure 7. January mean thermocline depth (feet). (See text for definition.)

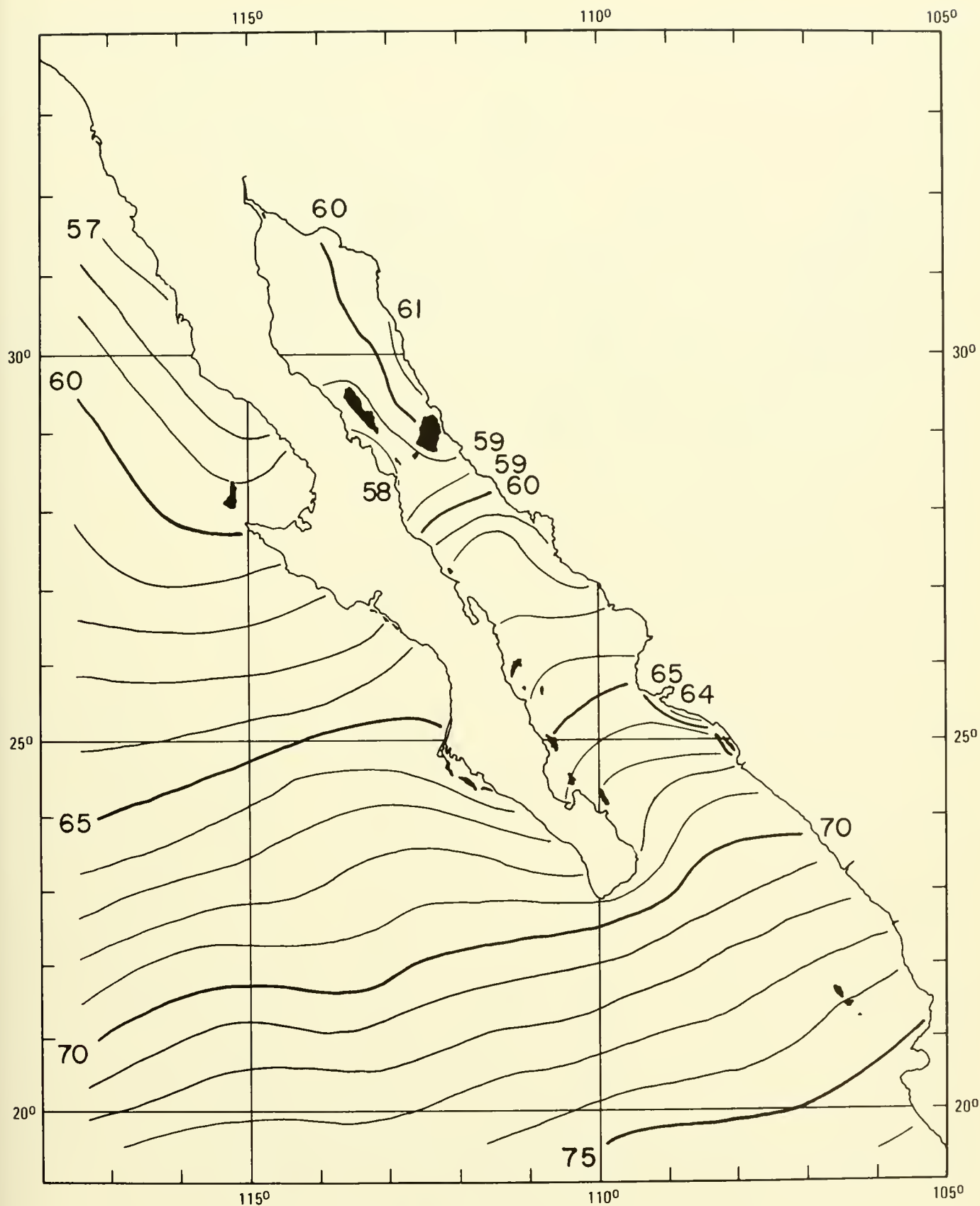


Figure 8. February mean sea surface temperatures (°F).

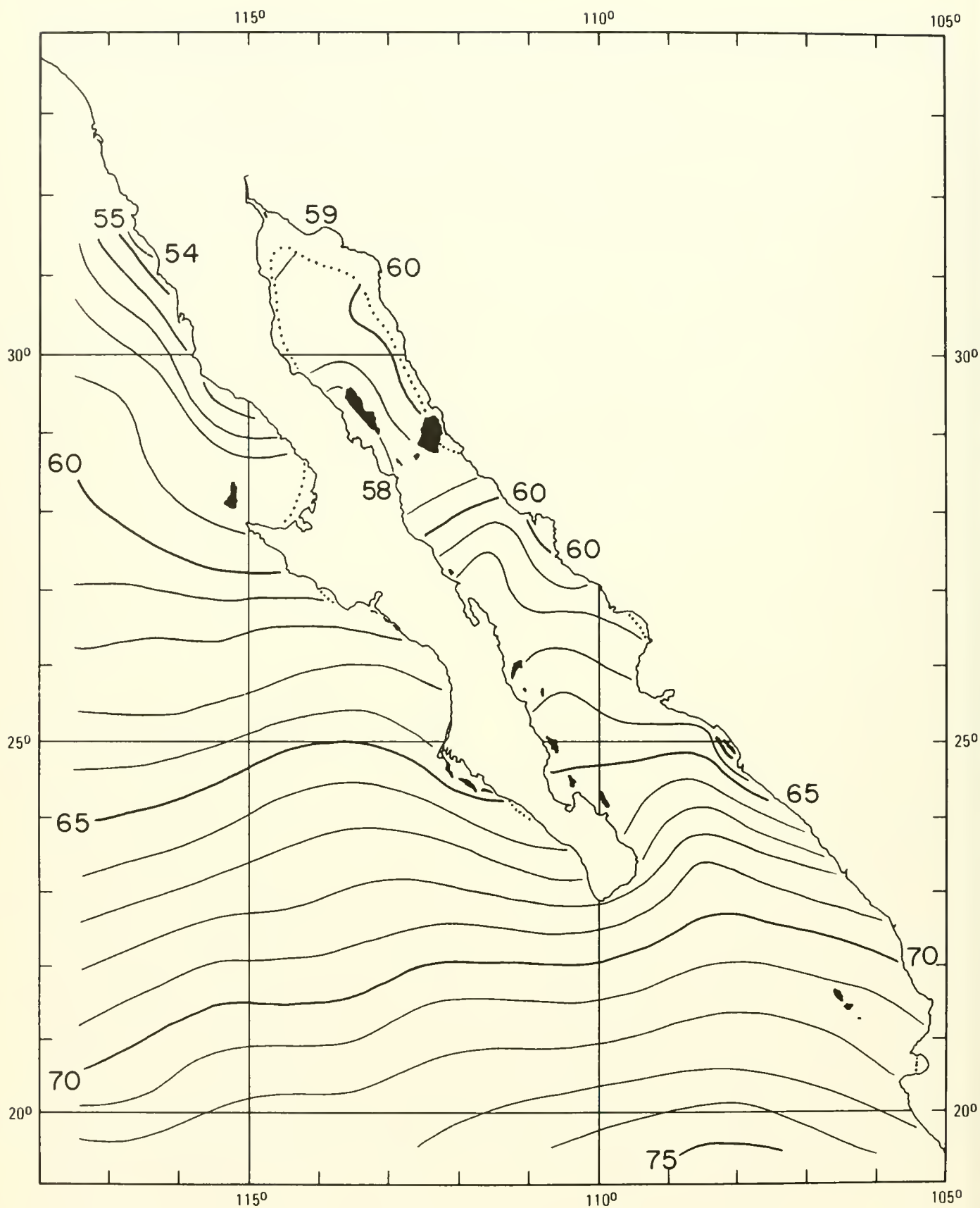


Figure 9. February mean temperatures ($^{\circ}$ F) at 100 feet.

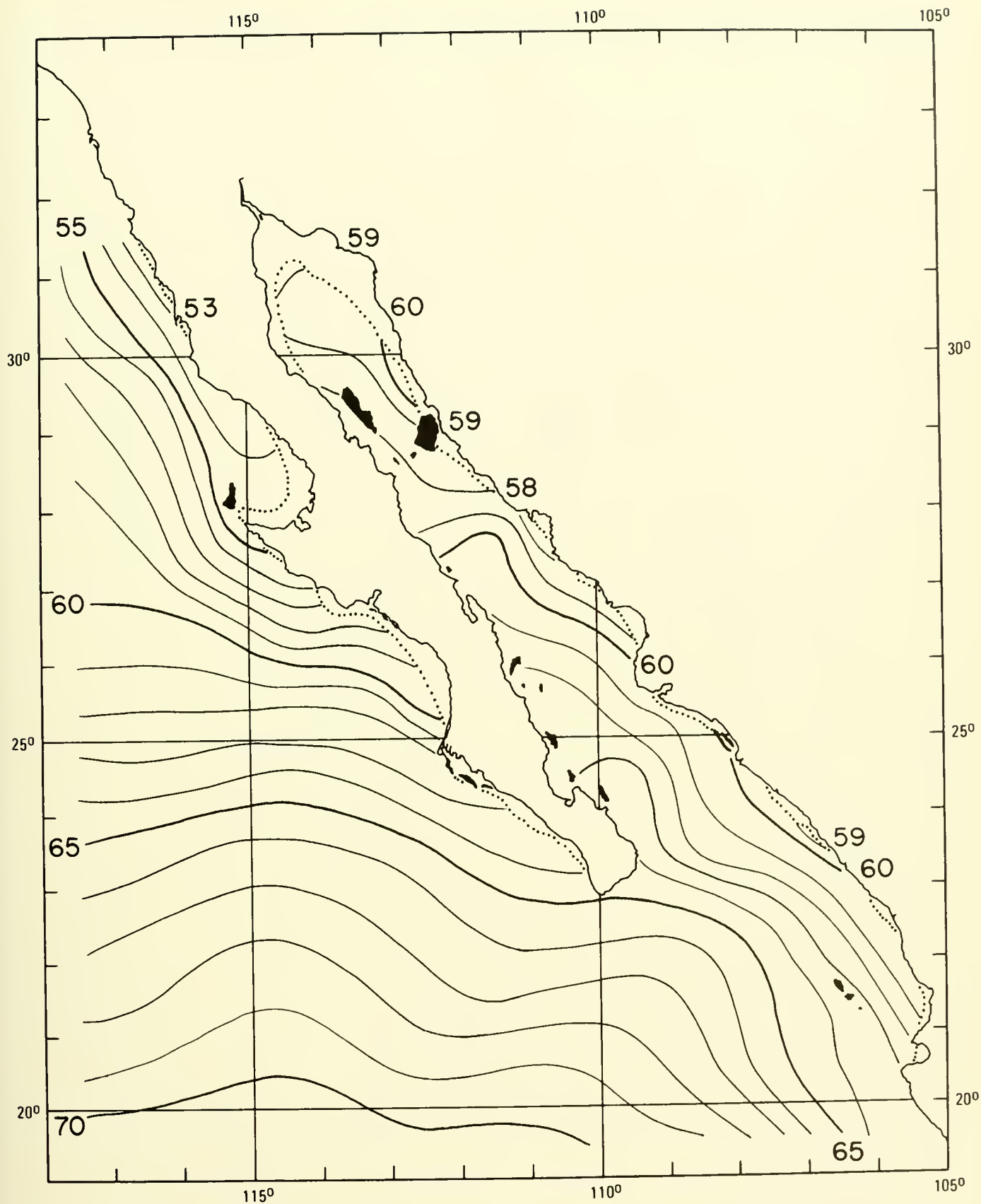


Figure 10. February mean temperatures (°F) at 200 feet.

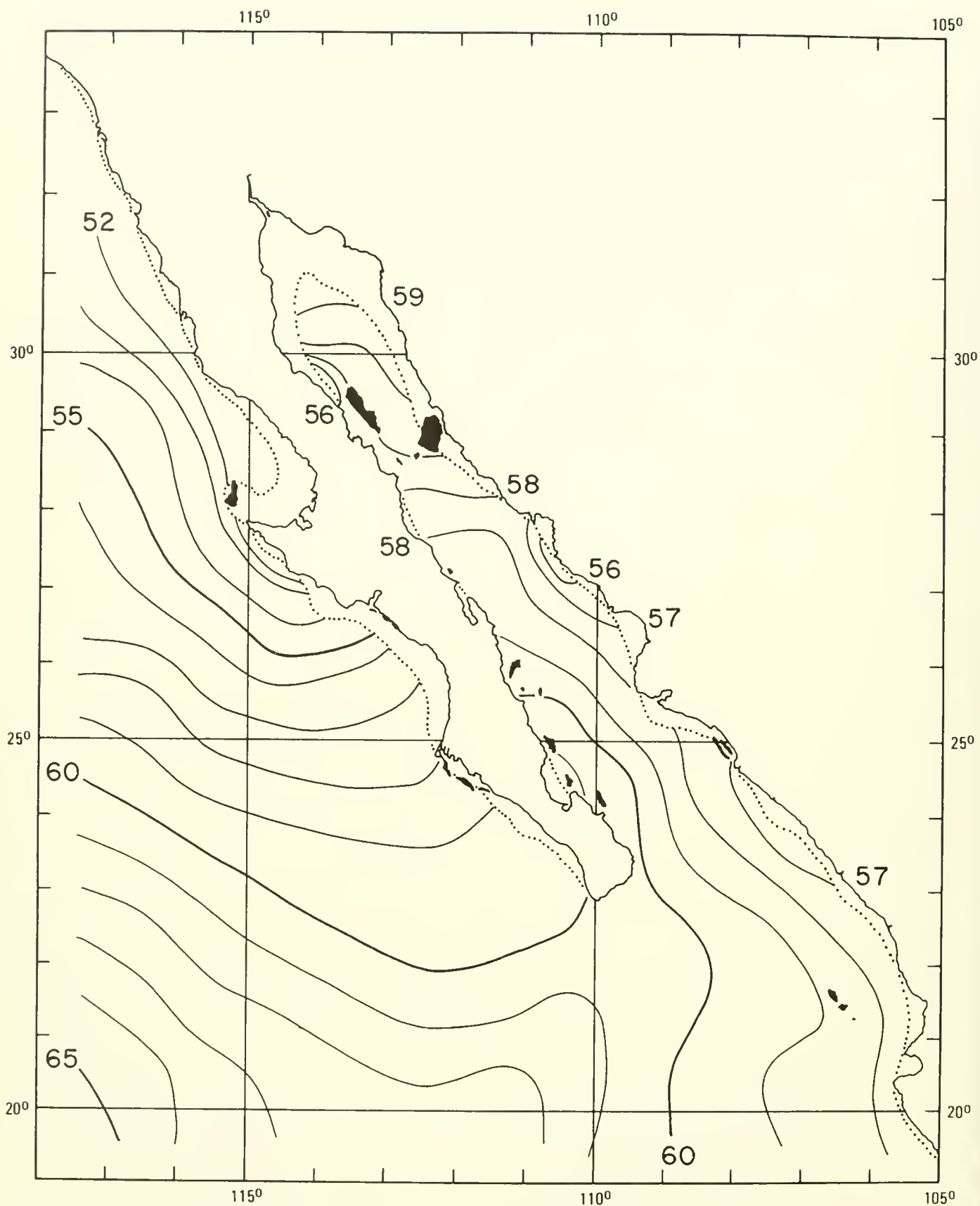


Figure 11. February mean temperatures ($^{\circ}\text{F}$) at 300 feet.

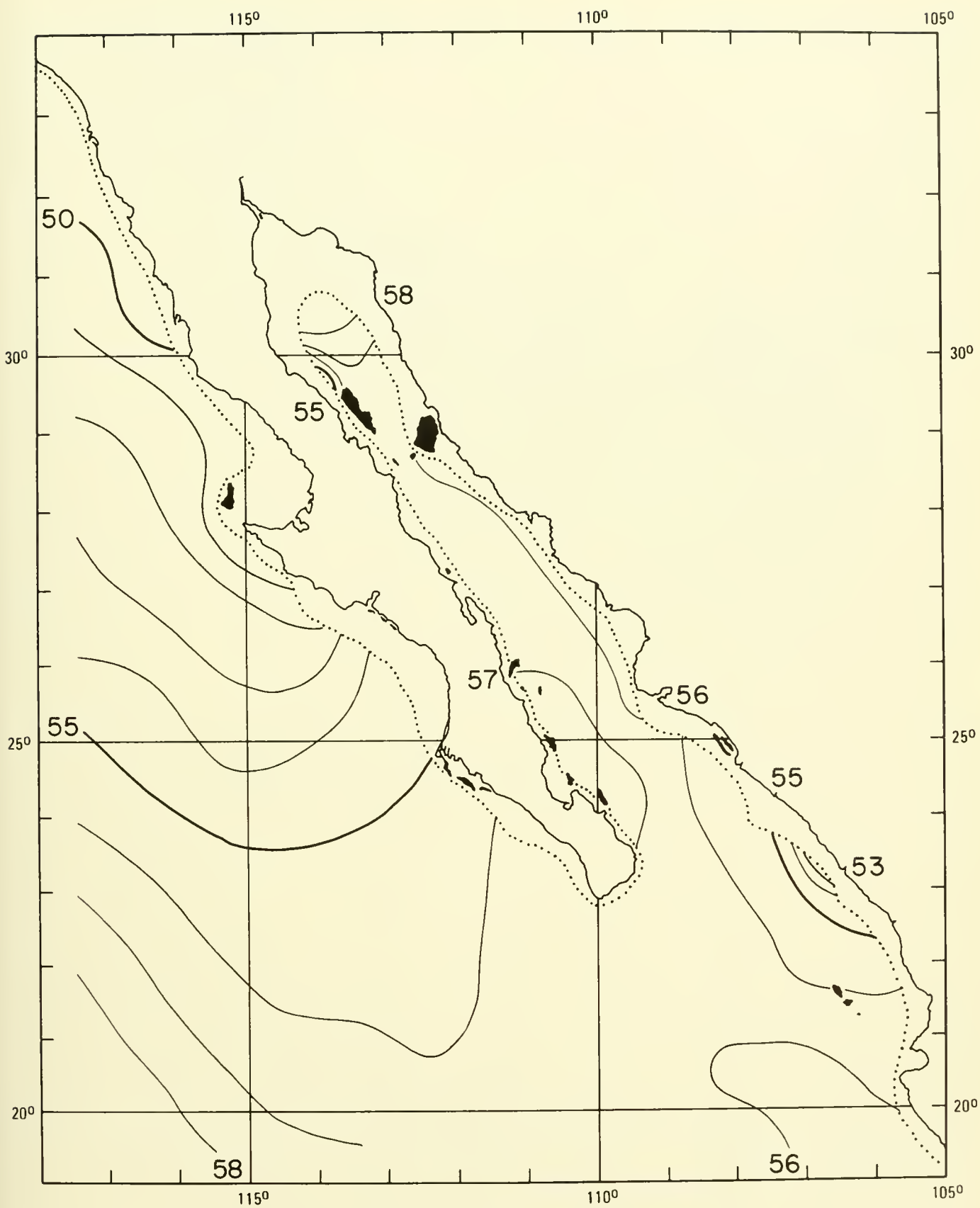


Figure 12. February mean temperatures ($^{\circ}$ F) at 400 feet.

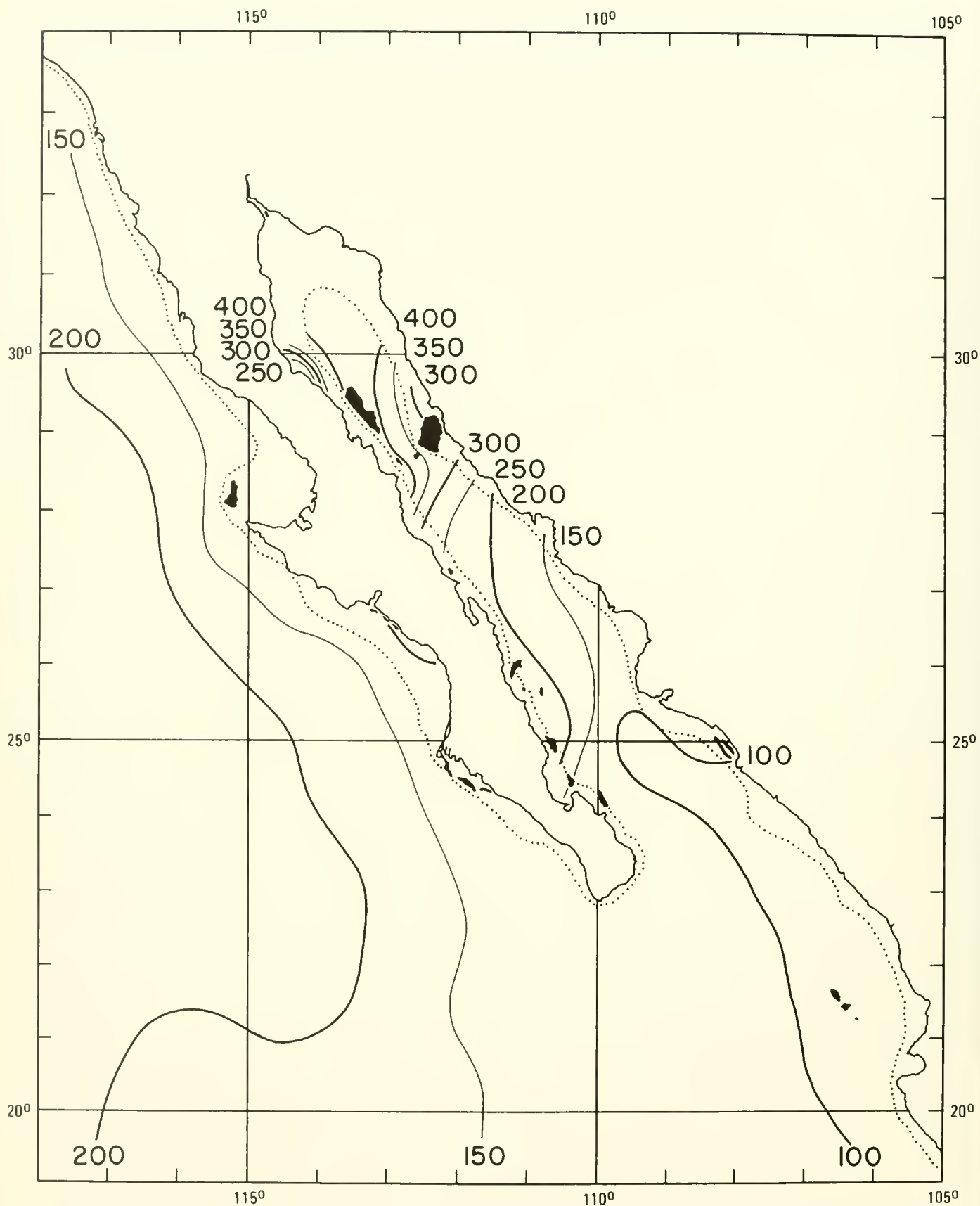


Figure 13. February mean thermocline depth (feet). (See text for definition.)

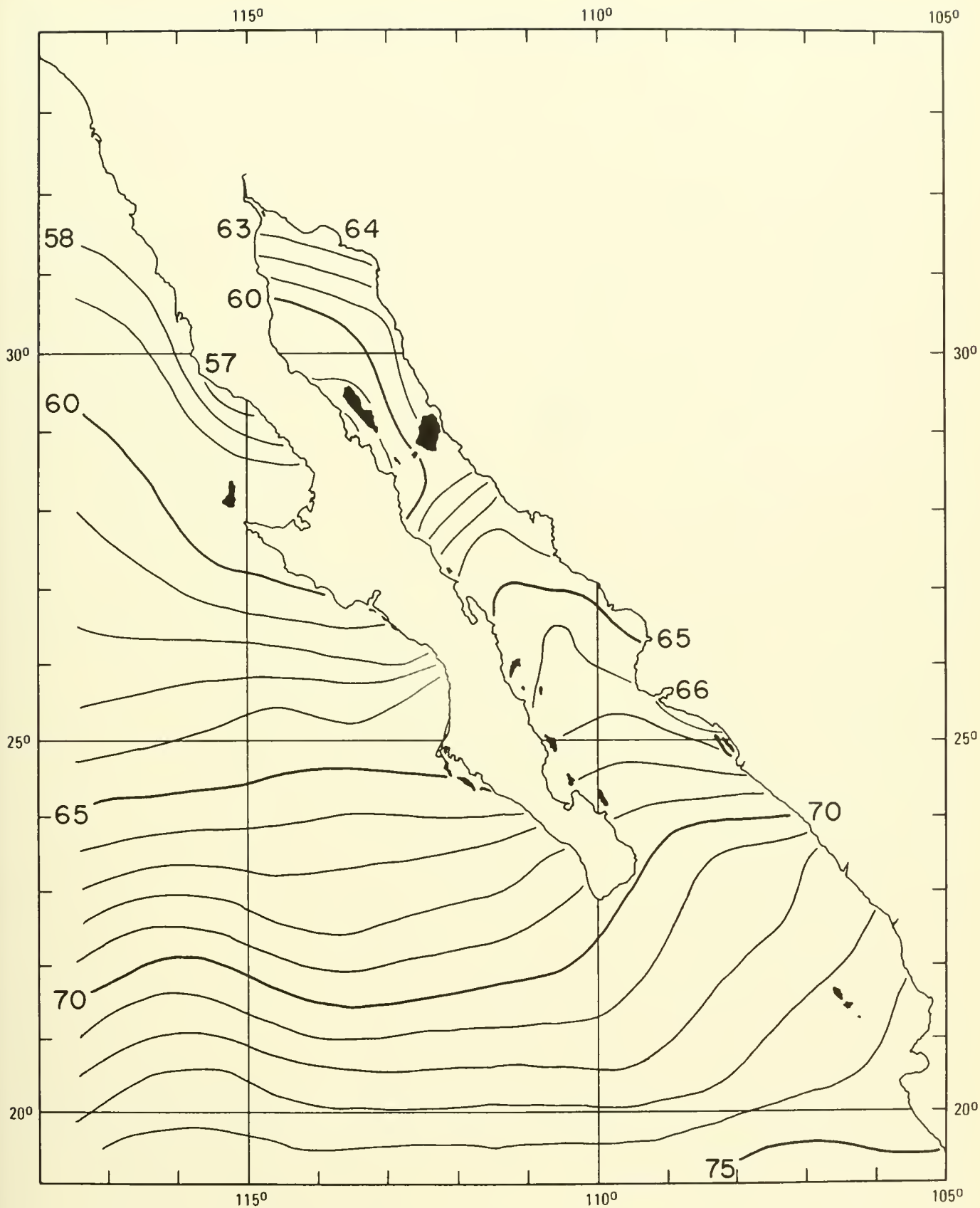


Figure 14. March mean sea surface temperatures (°F).

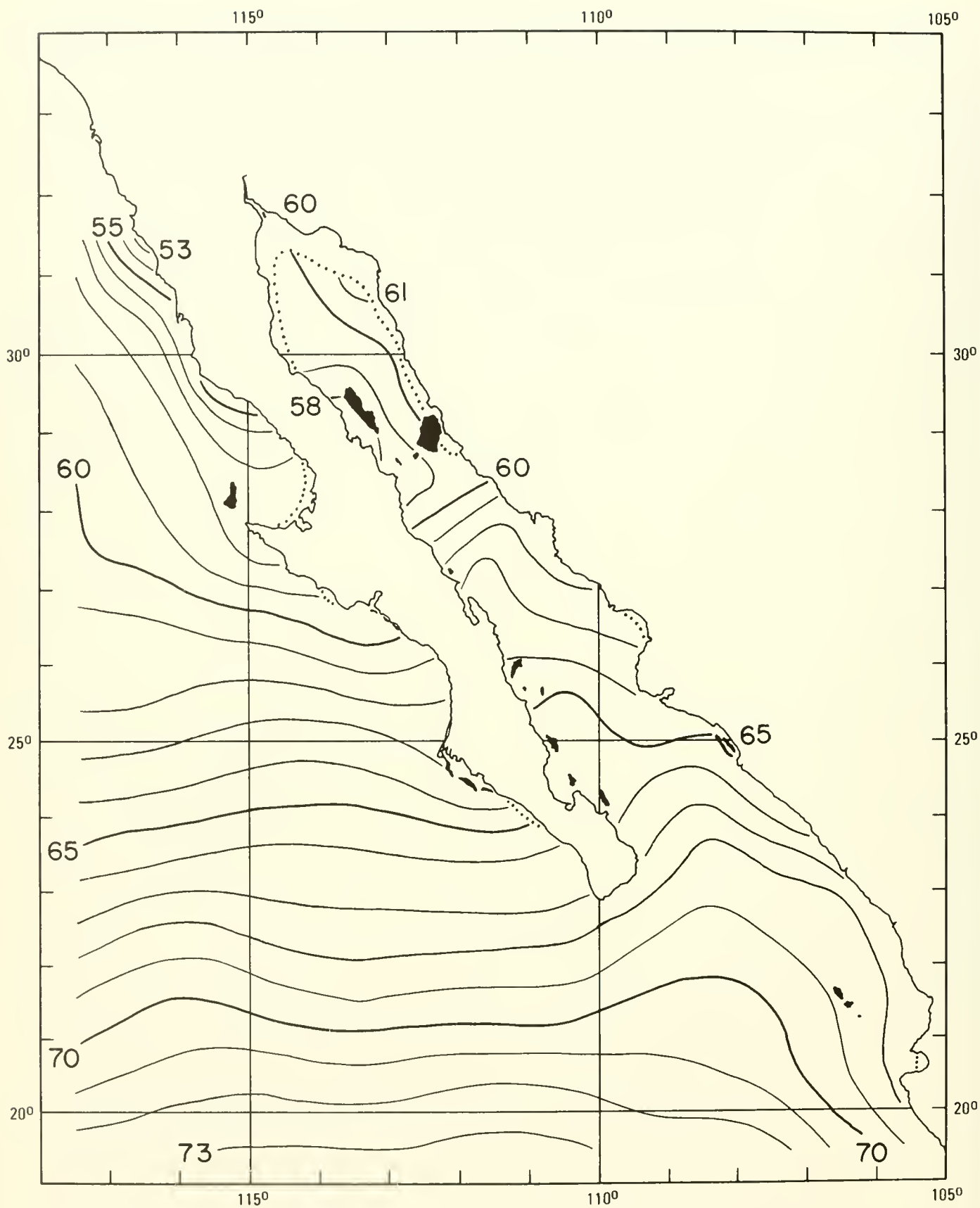


Figure 15. March mean temperatures ($^{\circ}$ F) at 100 feet.

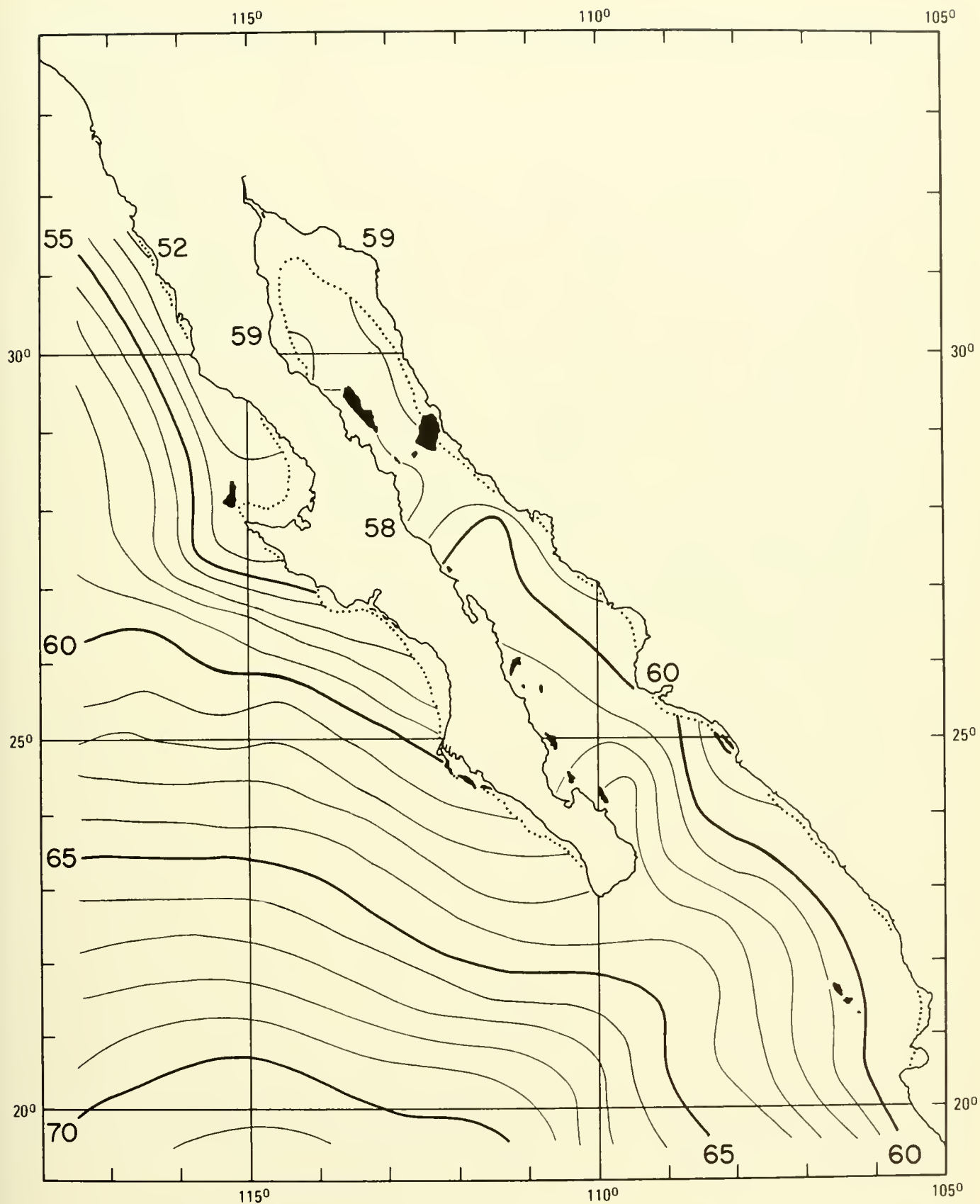


Figure 16. March mean temperatures ($^{\circ}$ F) at 200 feet.

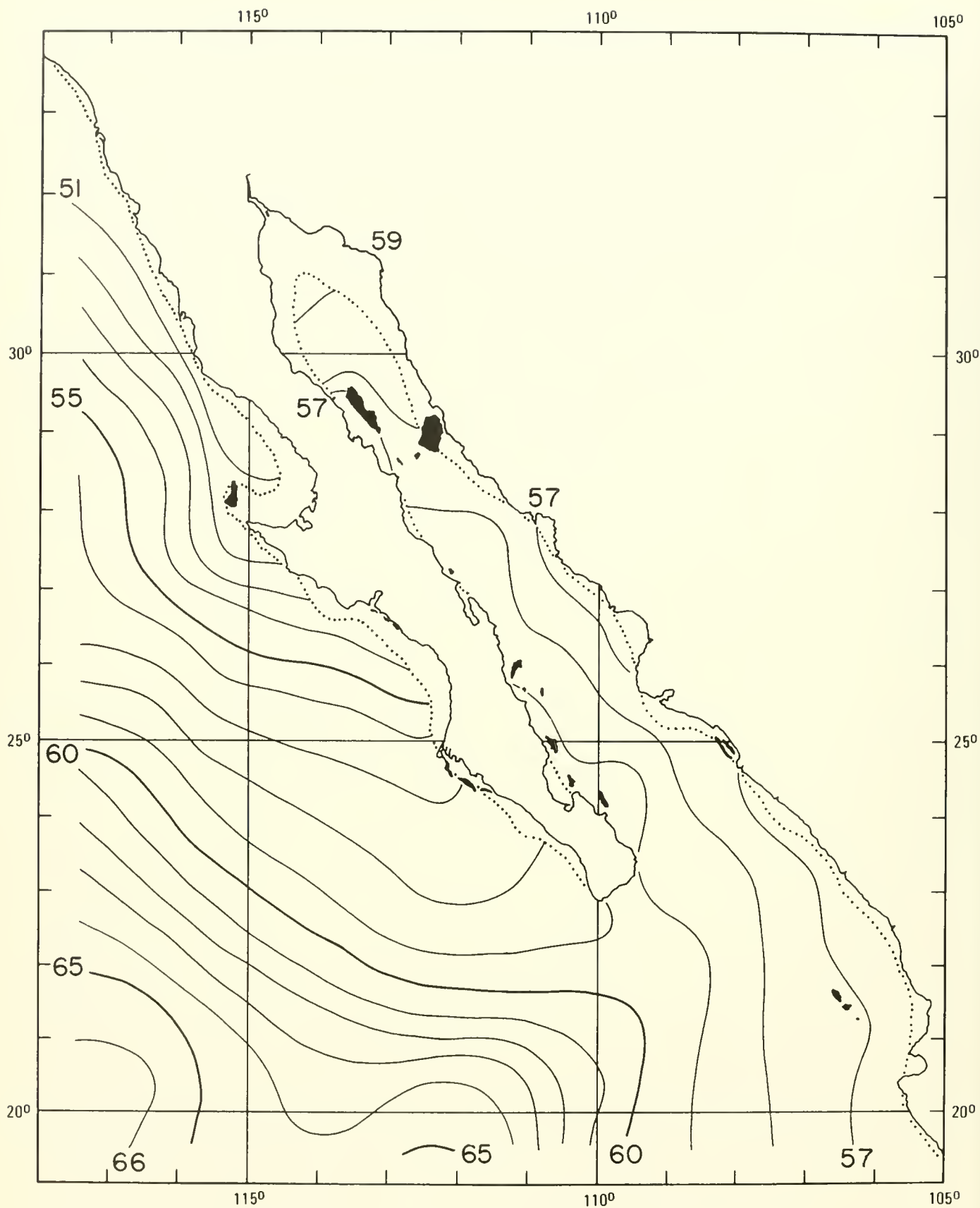


Figure 17. March mean temperatures ($^{\circ}$ F) at 300 feet.

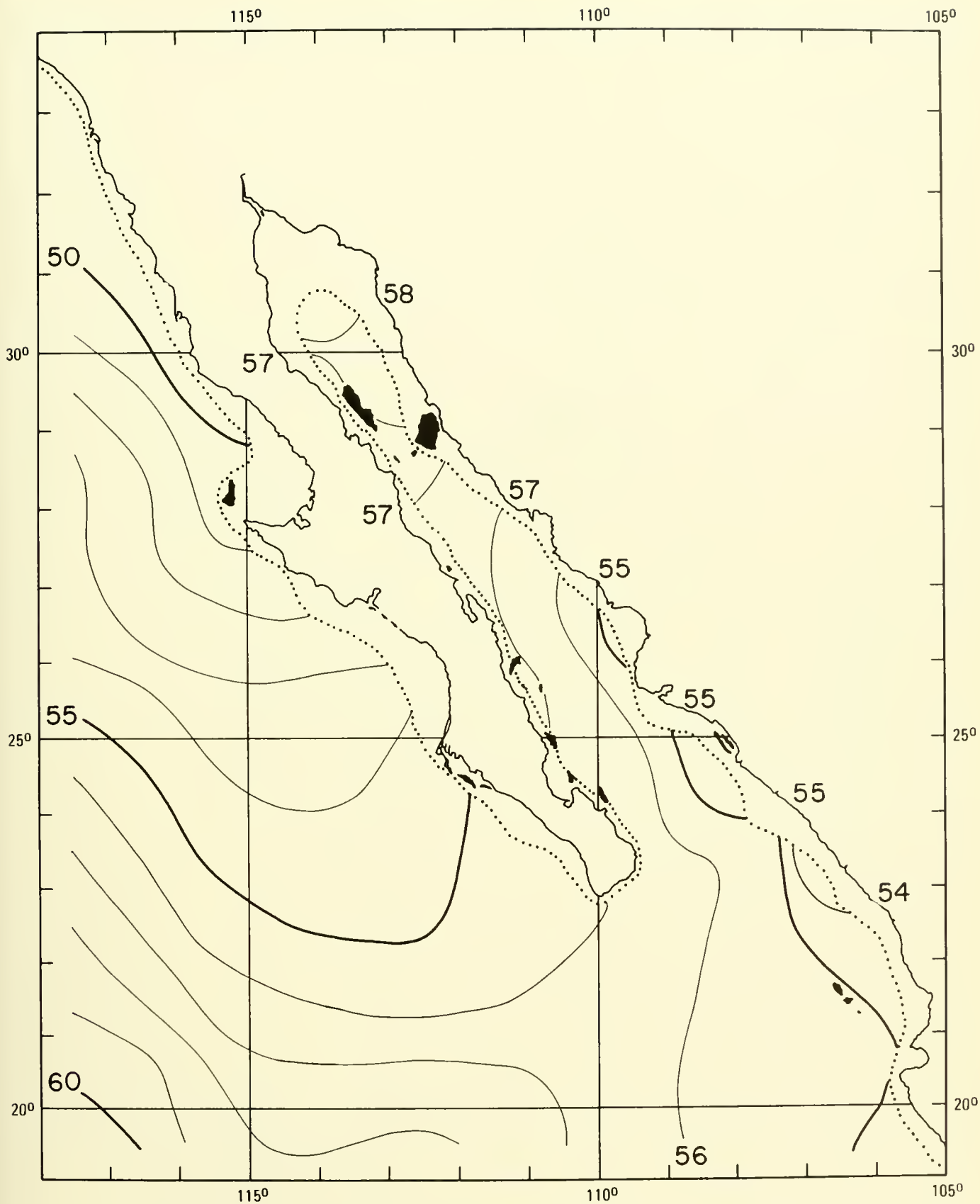


Figure 18. March mean temperatures ($^{\circ}$ F) at 400 feet.

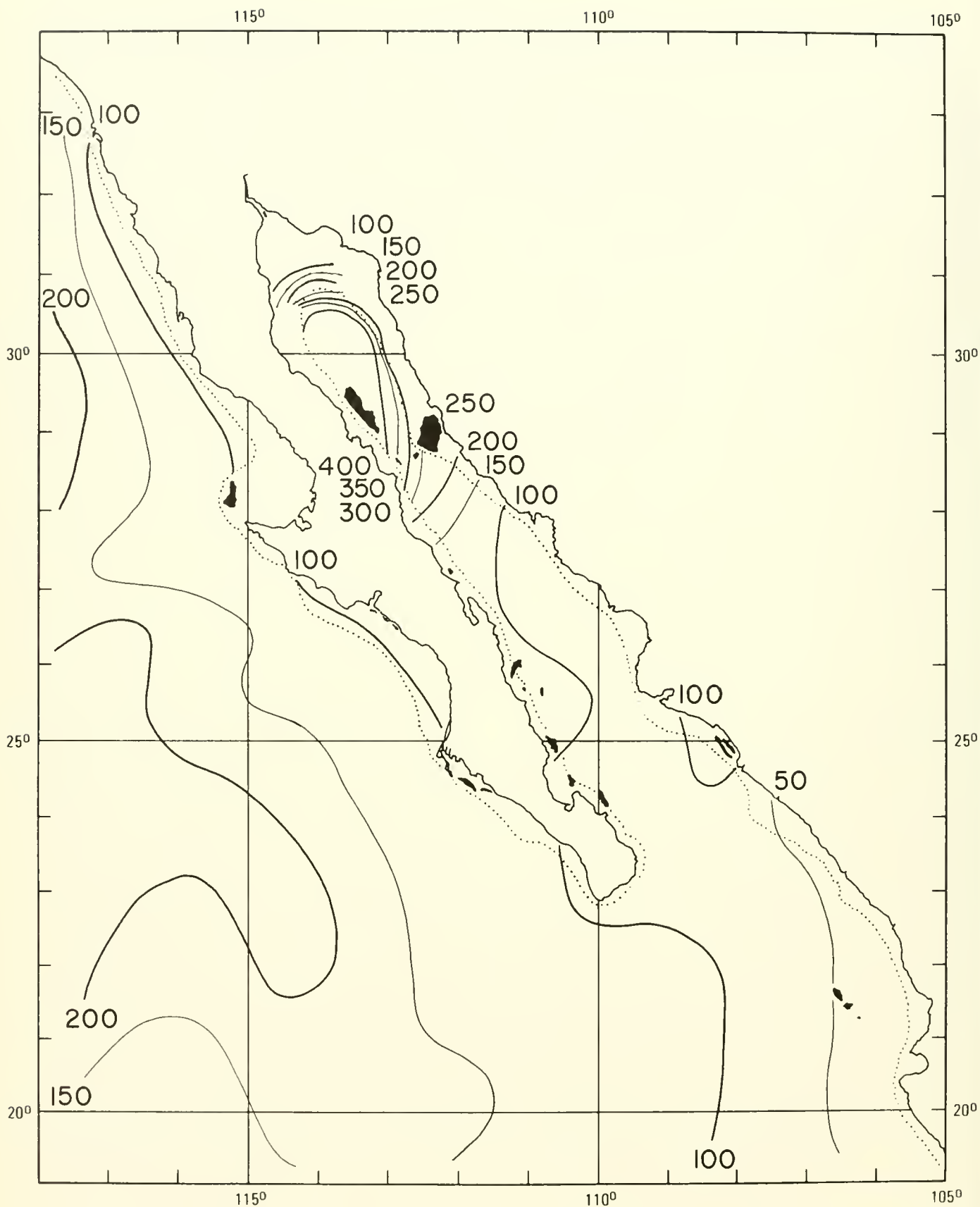


Figure 19. March mean thermocline depth (feet). (See text for definition.)

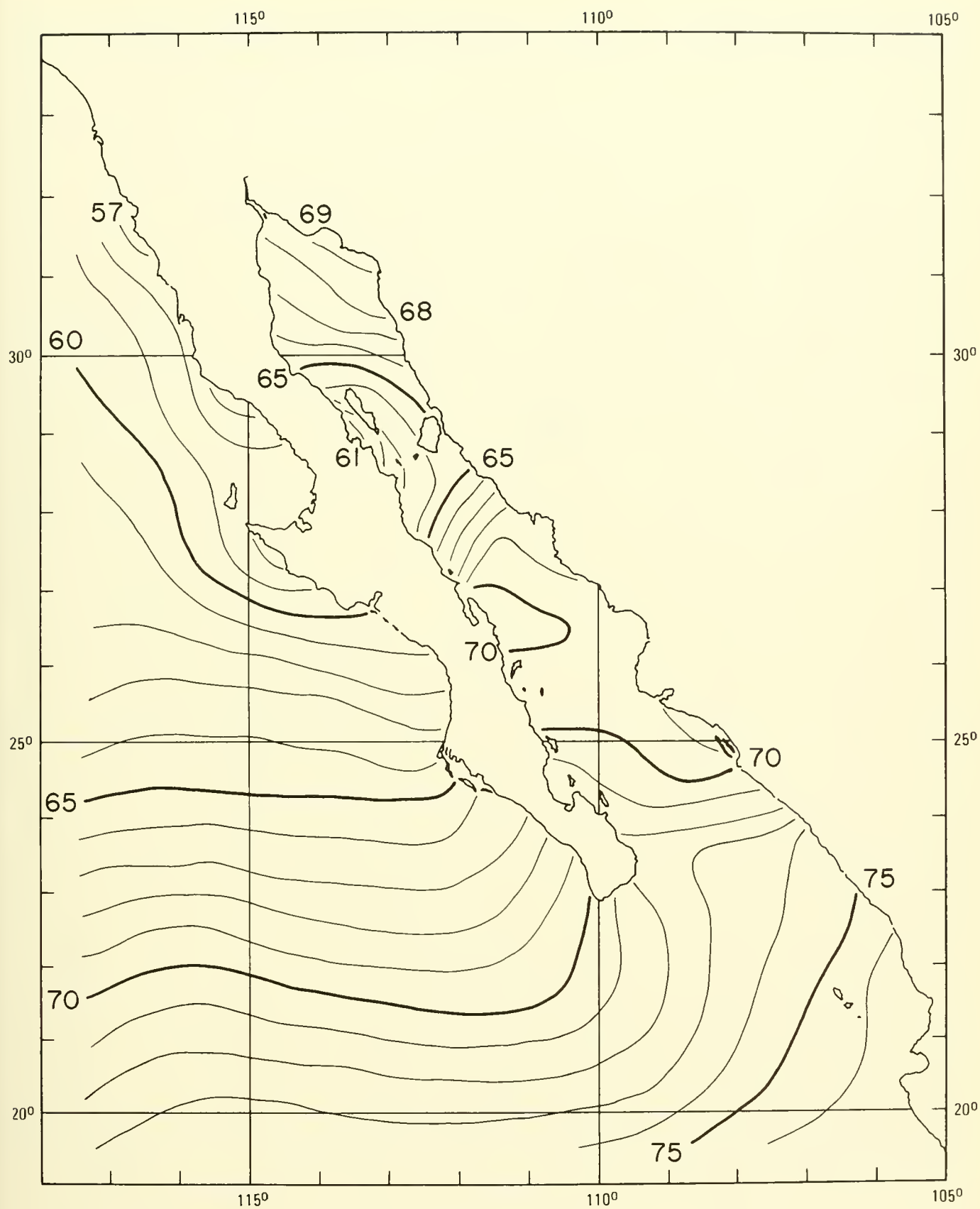


Figure 20. April mean sea surface temperatures (°F).

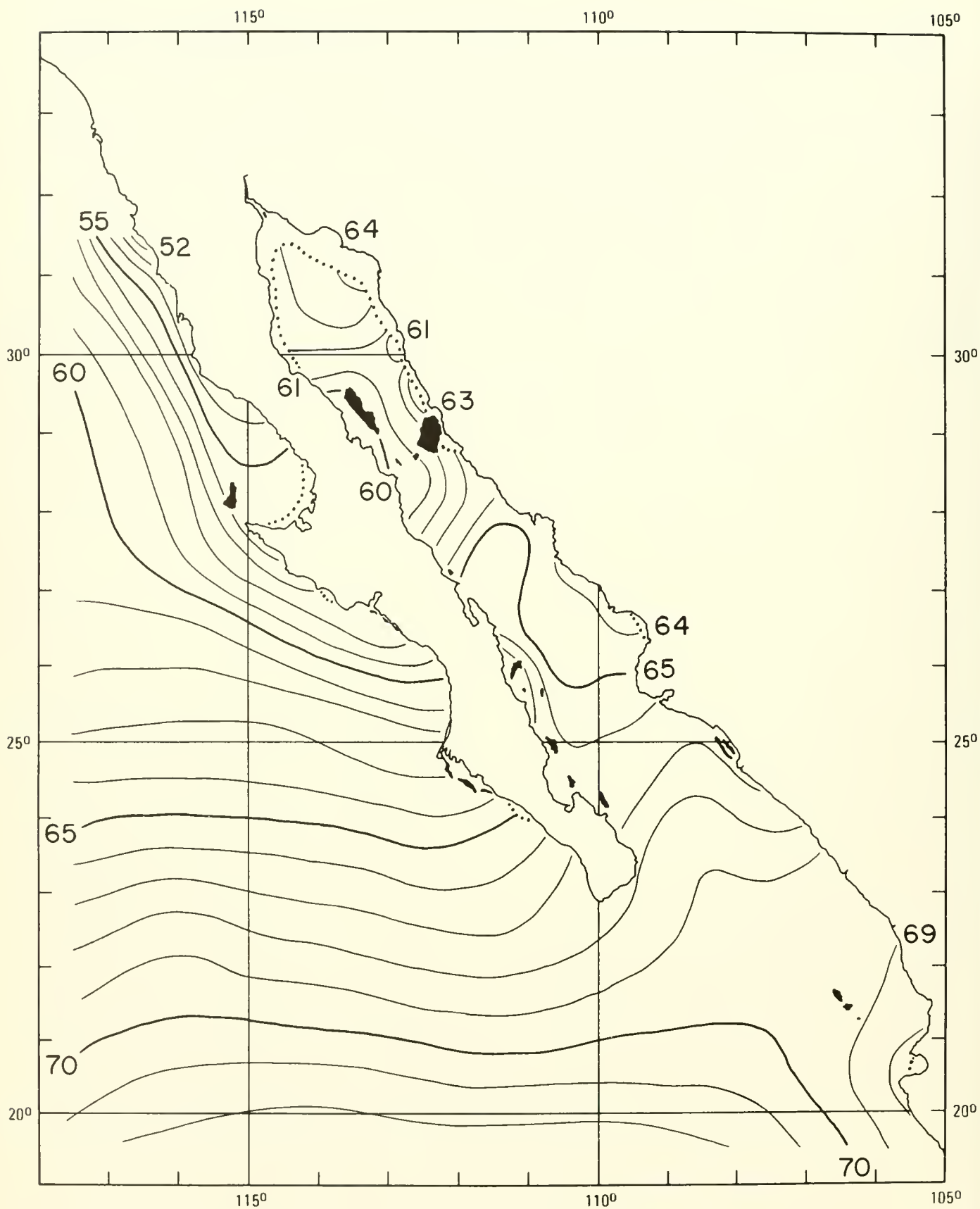


Figure 21. April mean temperatures ($^{\circ}$ F) at 100 feet.

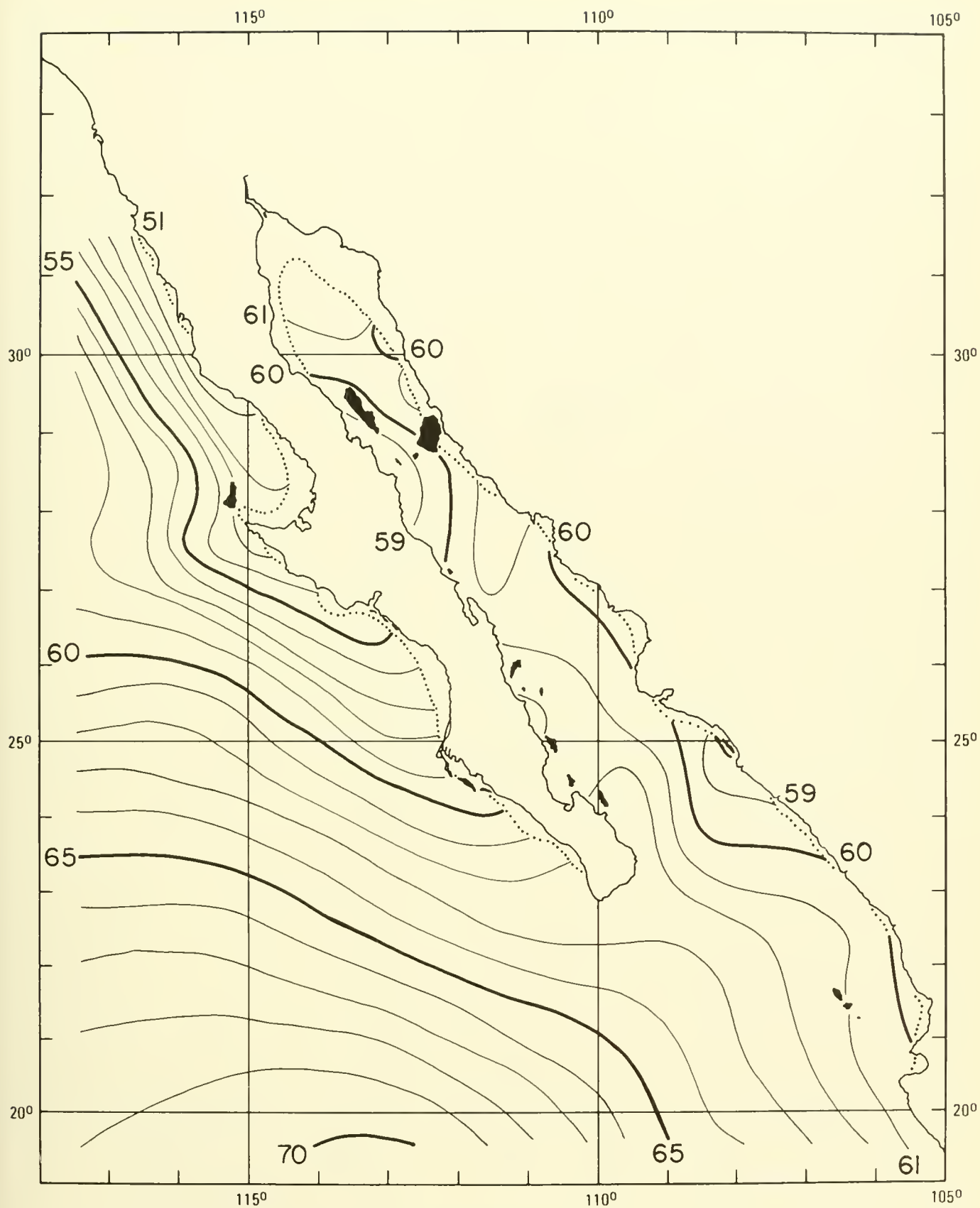


Figure 22. April mean temperatures ($^{\circ}$ F) at 200 feet.

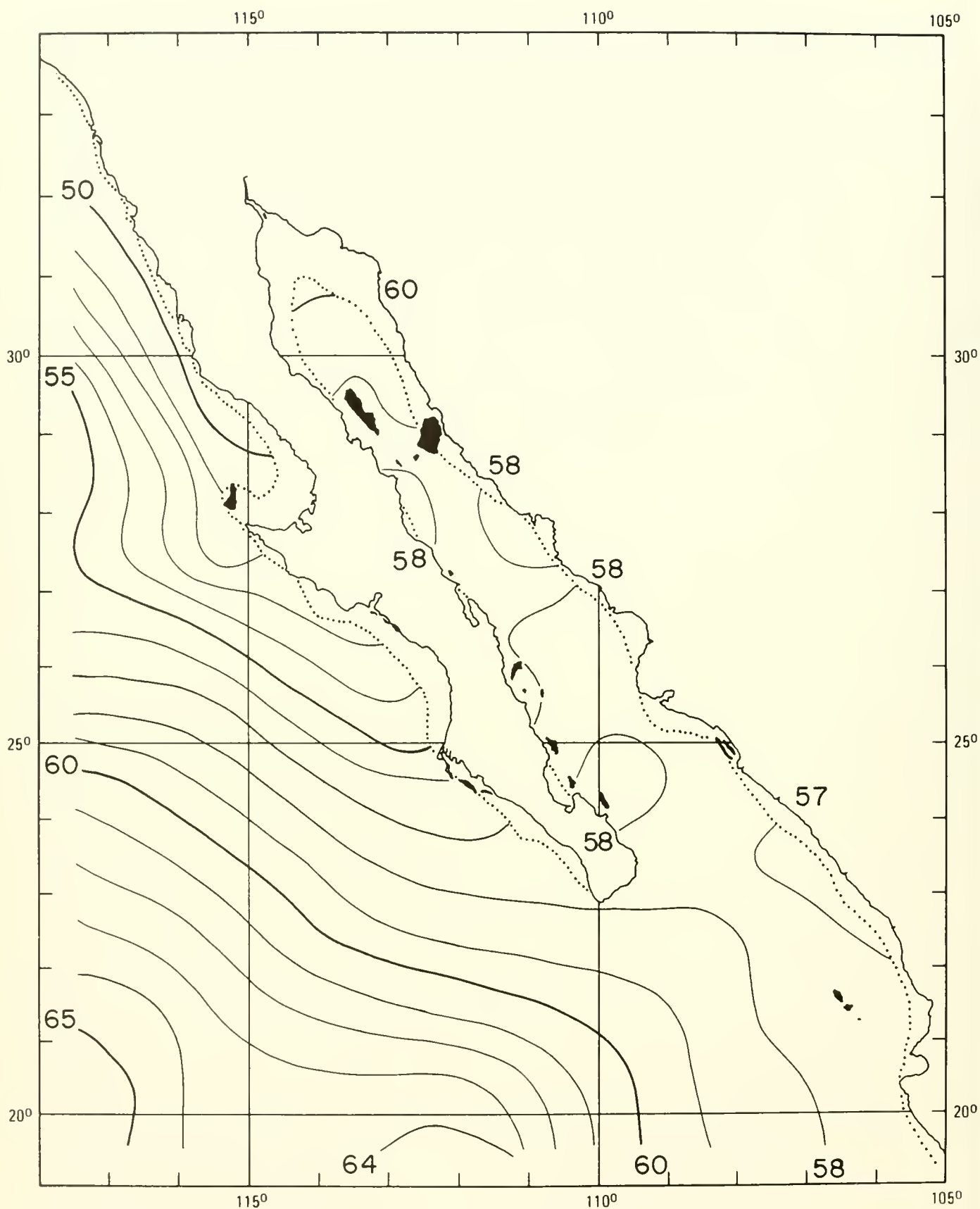


Figure 23. April mean temperatures ($^{\circ}$ F) at 300 feet.

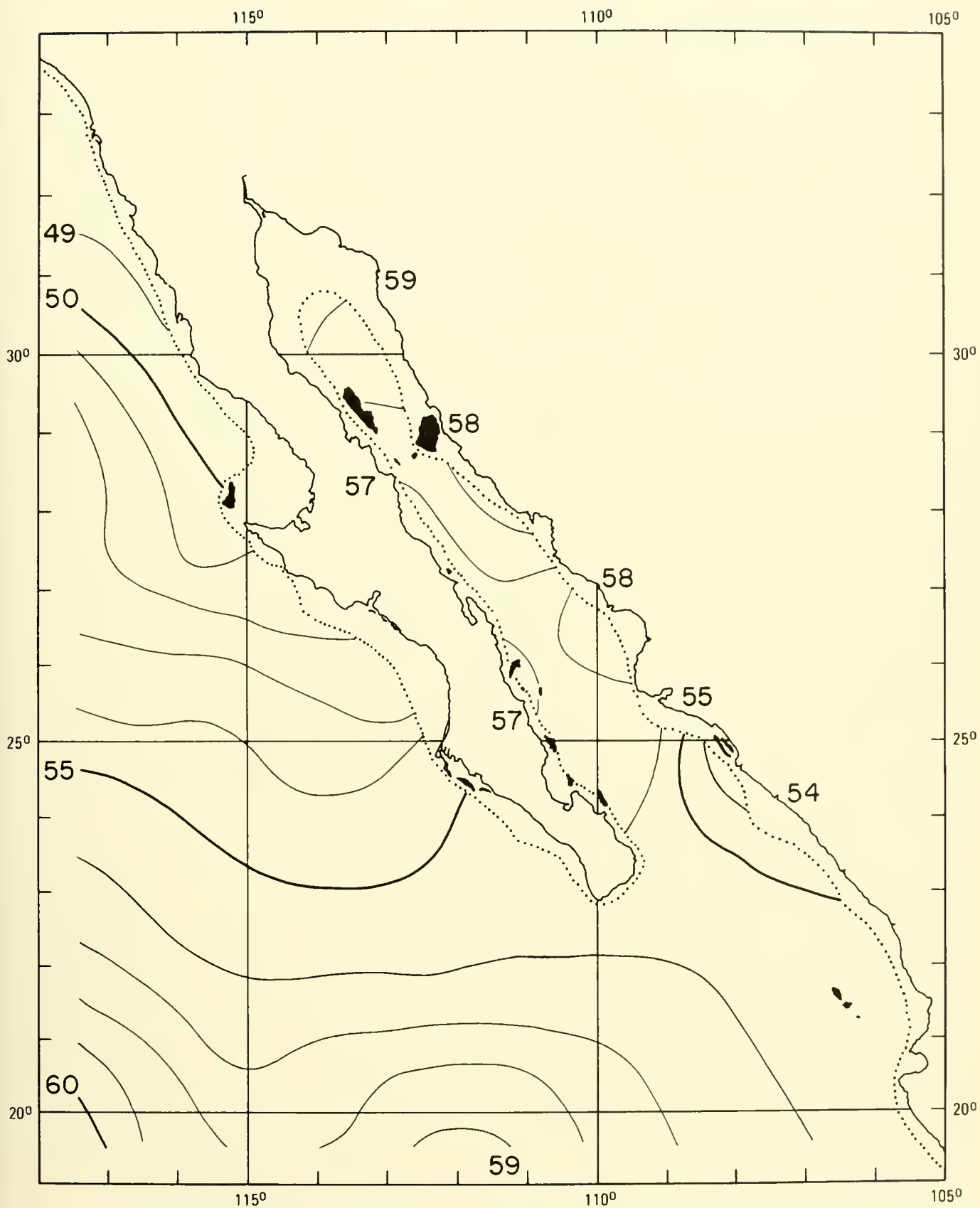


Figure 24. April mean temperatures ($^{\circ}$ F) at 400 feet.

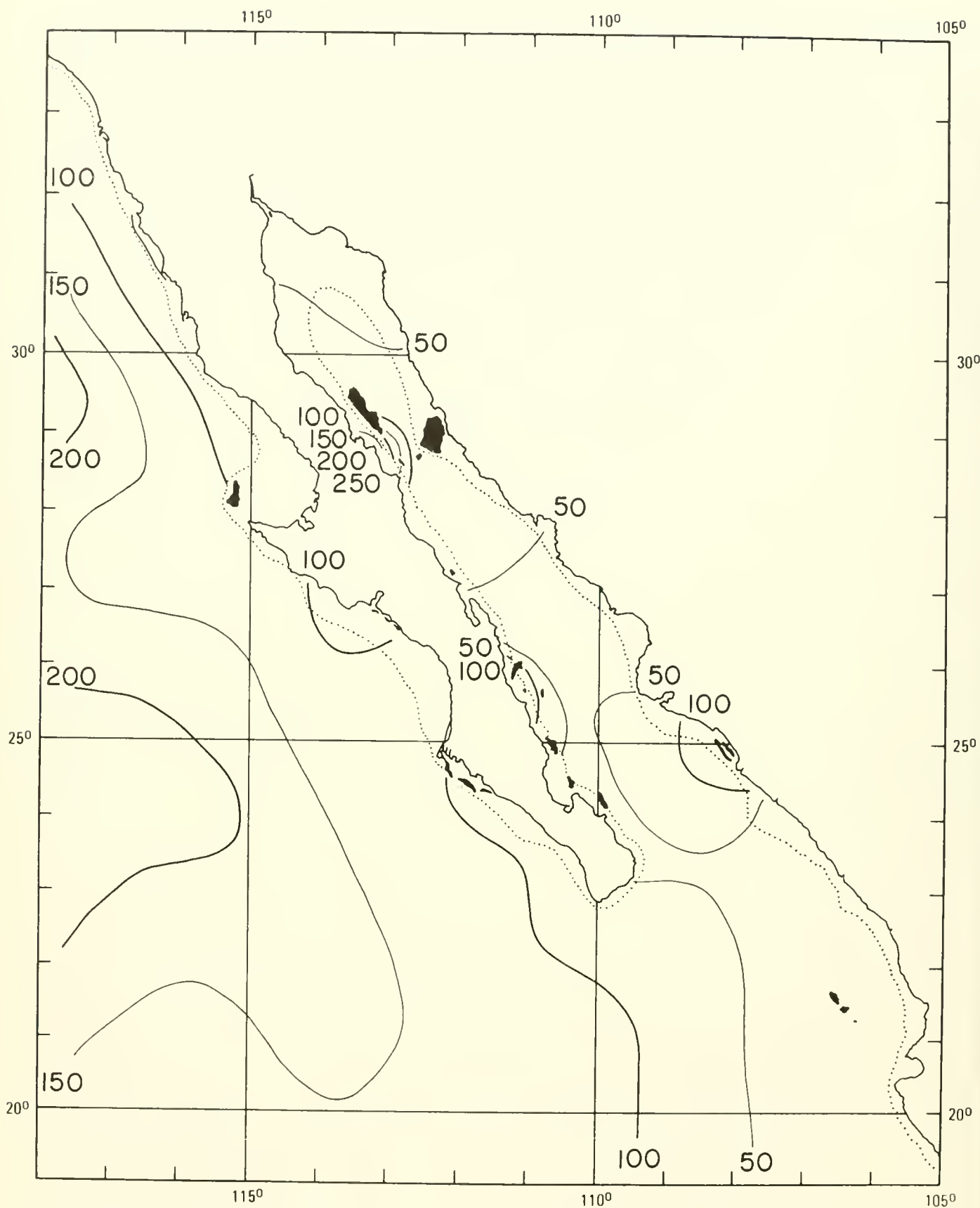


Figure 25. April mean thermocline depth (feet). (See text for definition.)

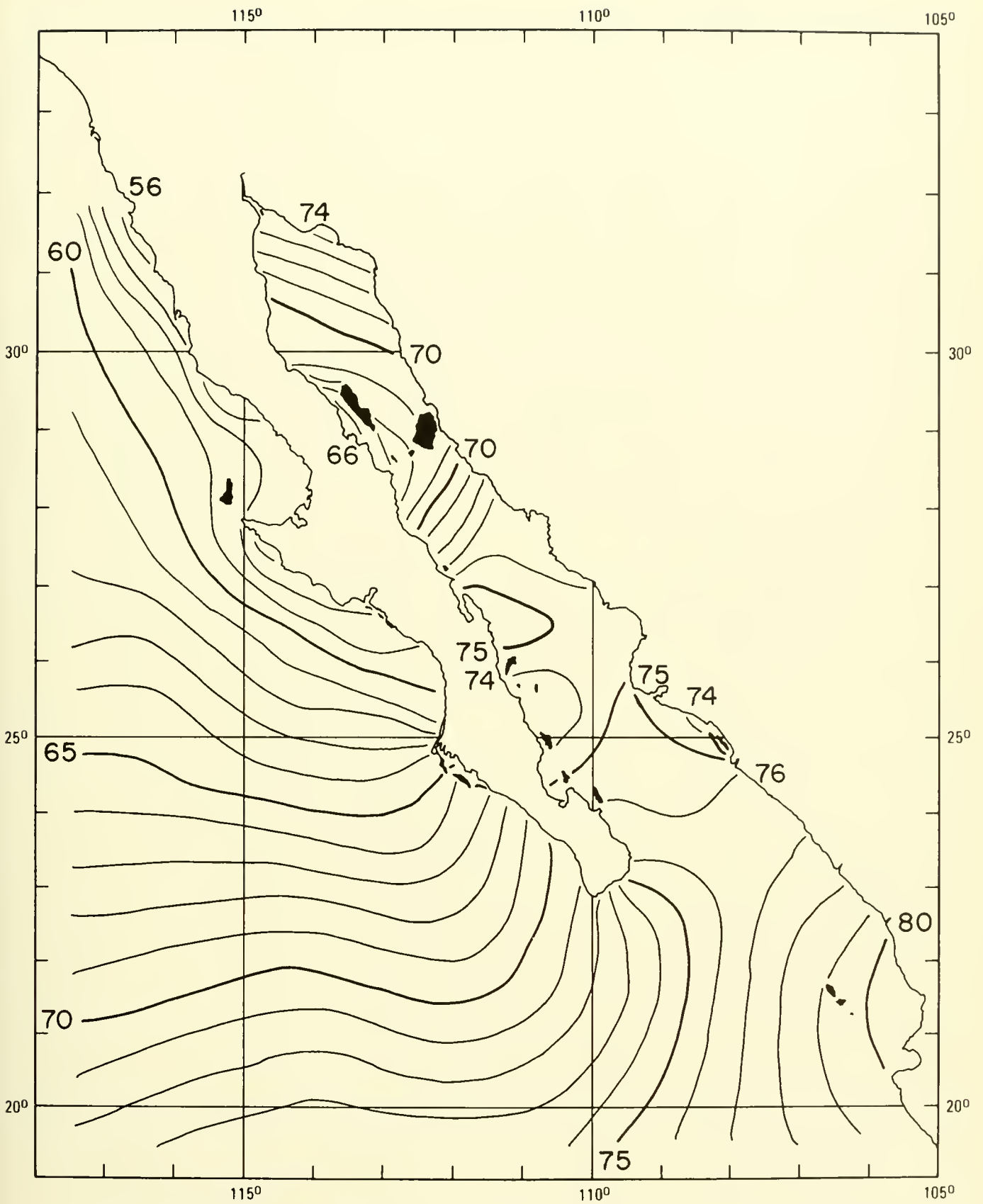


Figure 26. May mean sea surface temperatures (°F).

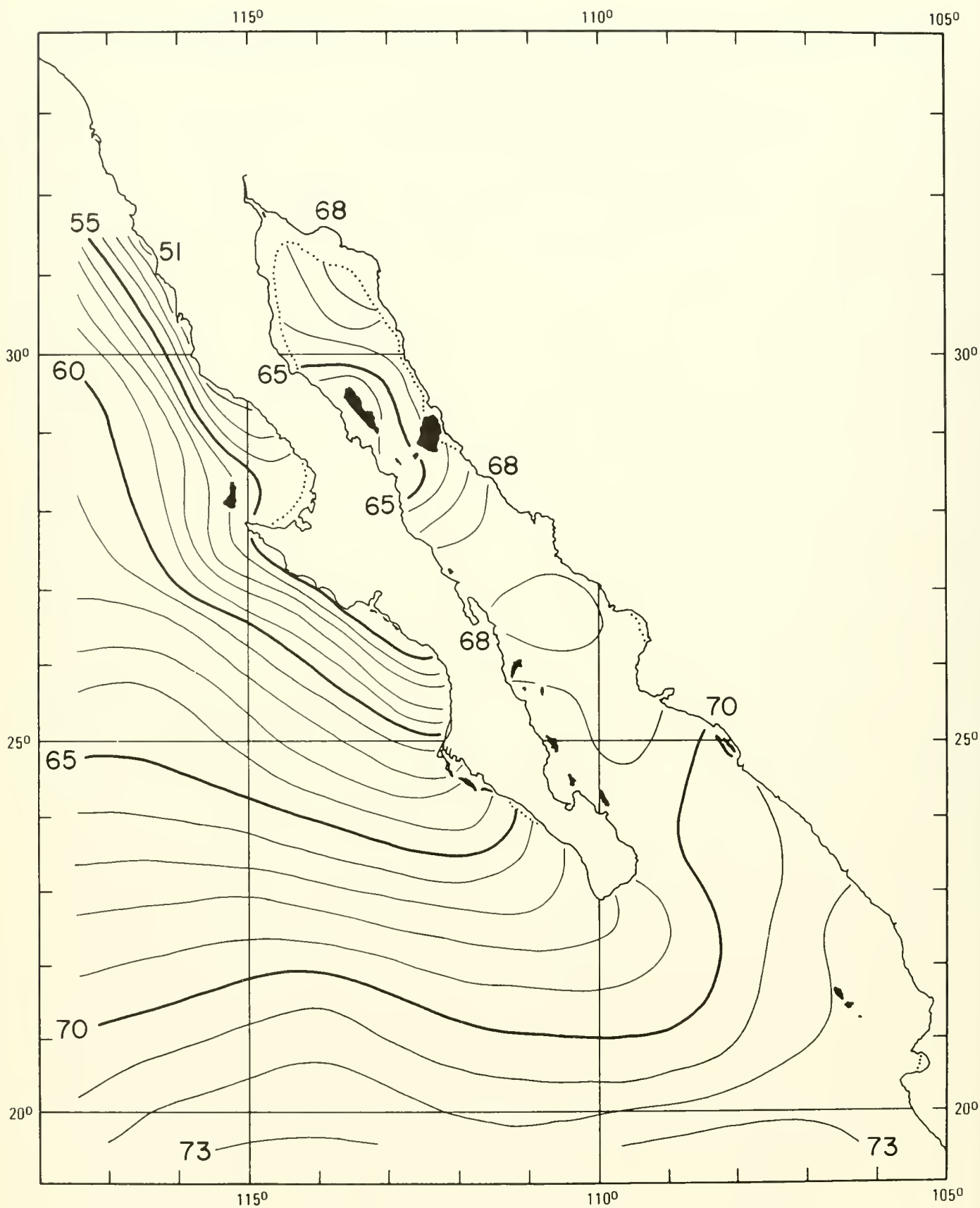


Figure 27. May mean temperatures ($^{\circ}$ F) at 100 feet.

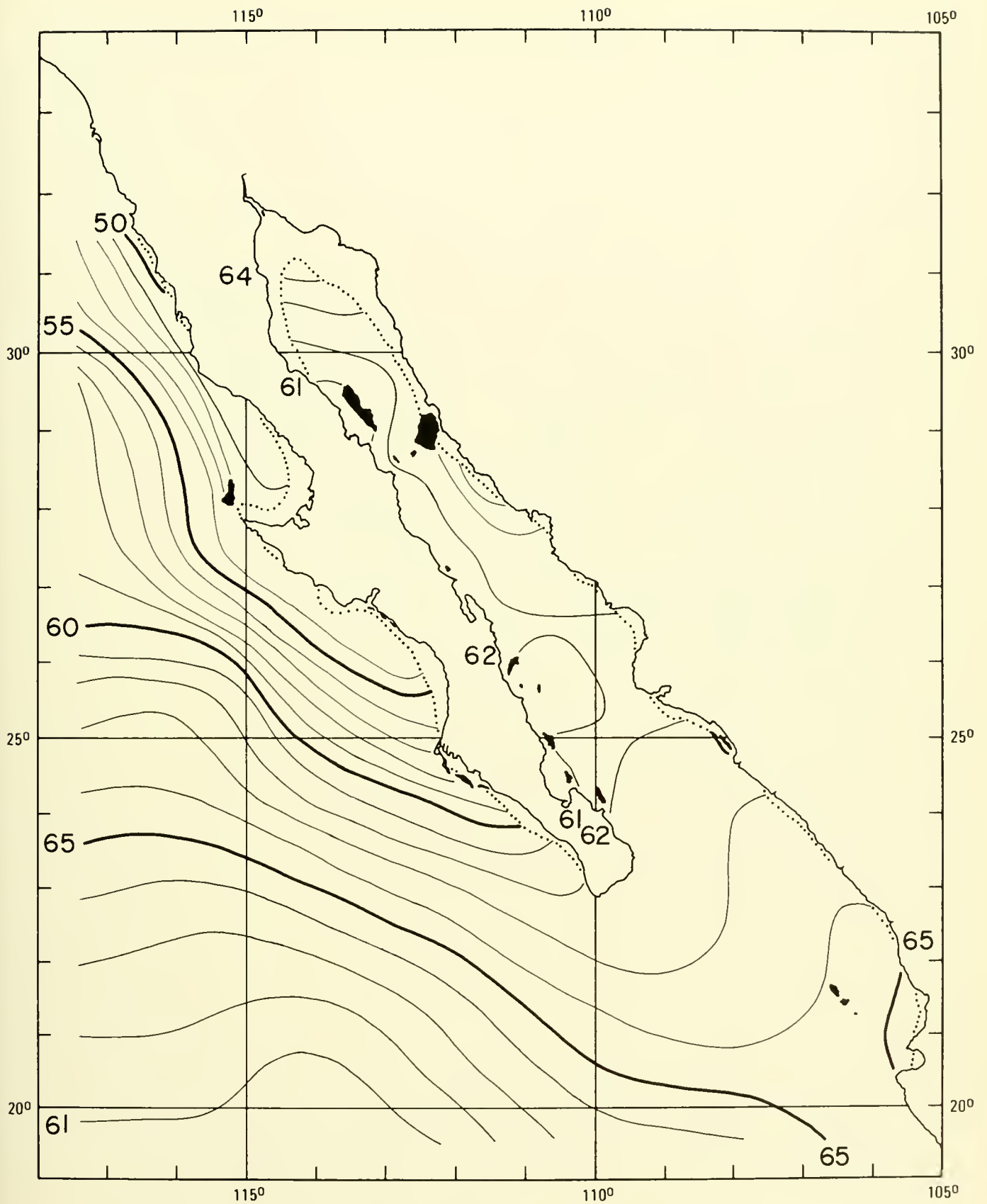


Figure 28. May mean temperatures ($^{\circ}\text{F}$) at 200 feet.

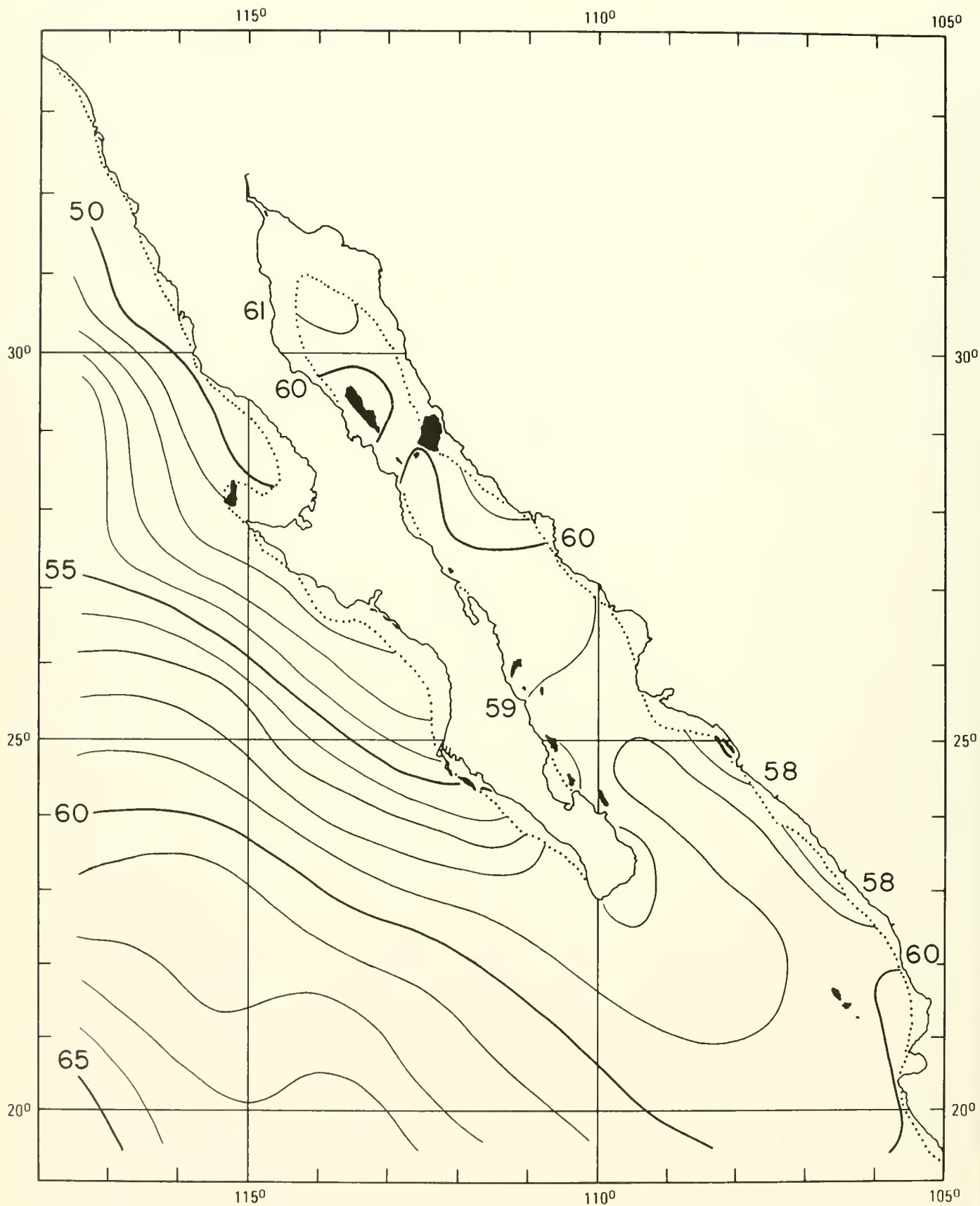


Figure 29. May mean temperatures (°F) at 300 feet.

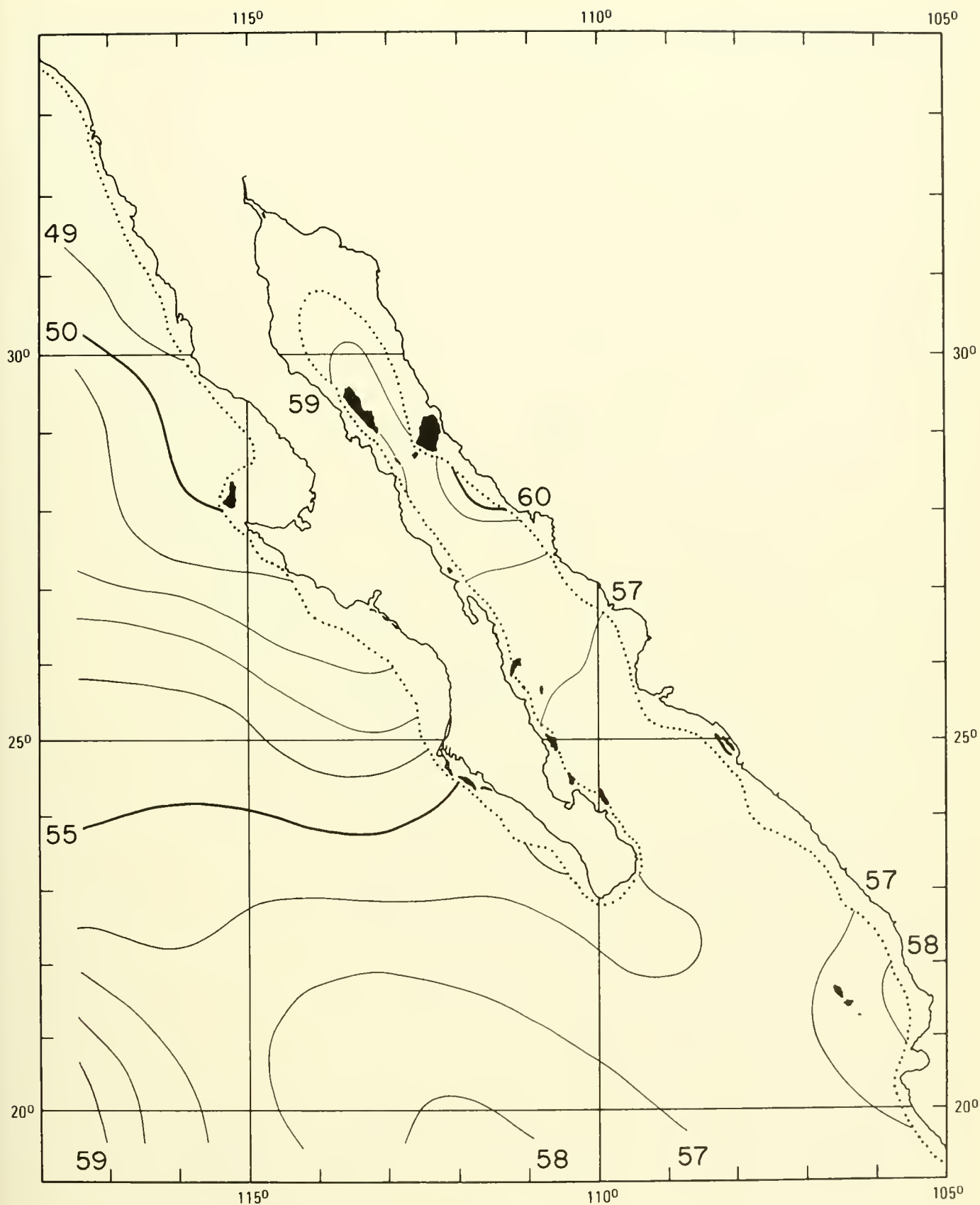


Figure 30. May mean temperatures ($^{\circ}$ F) at 400 feet.

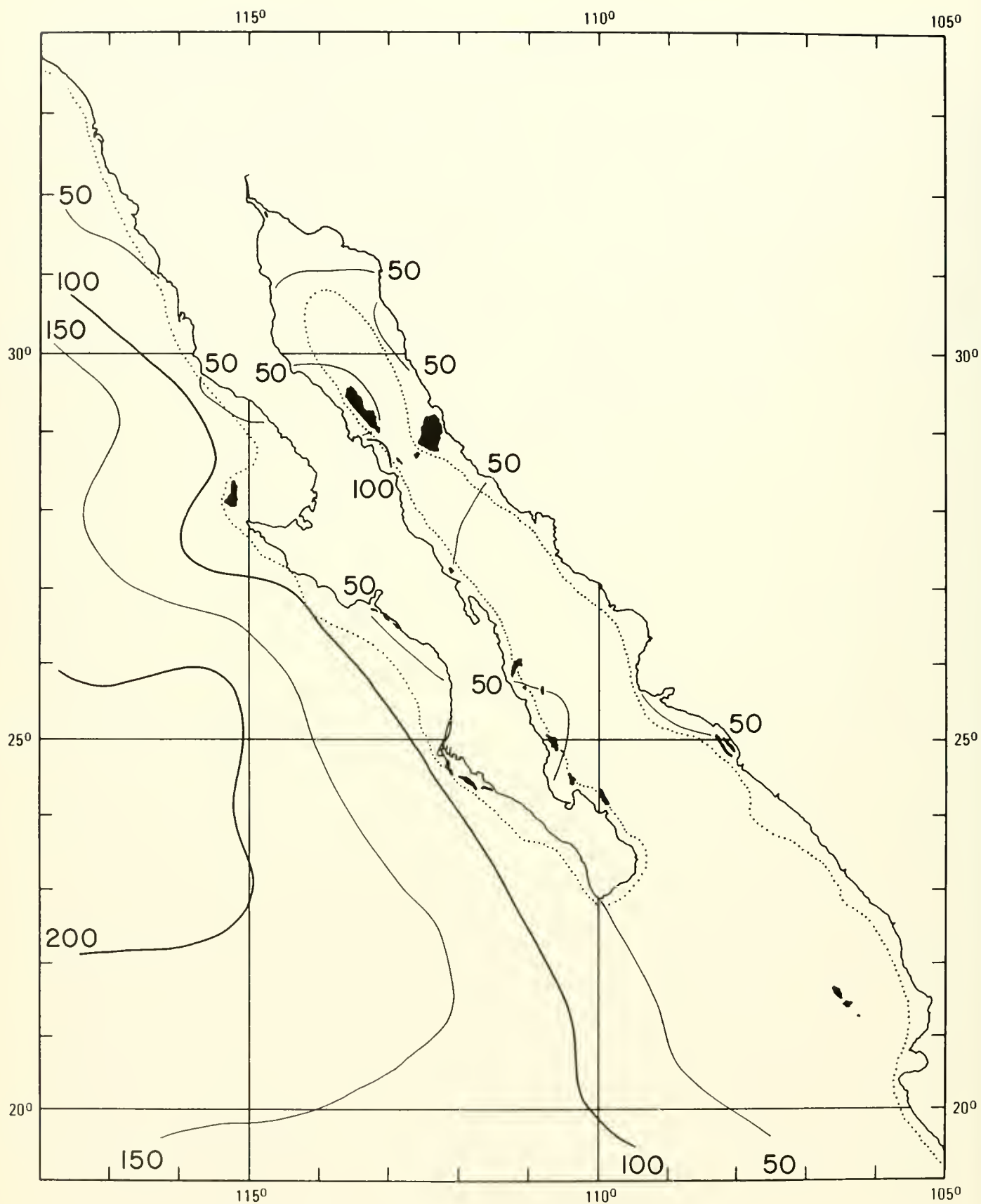


Figure 31. May mean thermocline depth (feet). (See text for definition.)

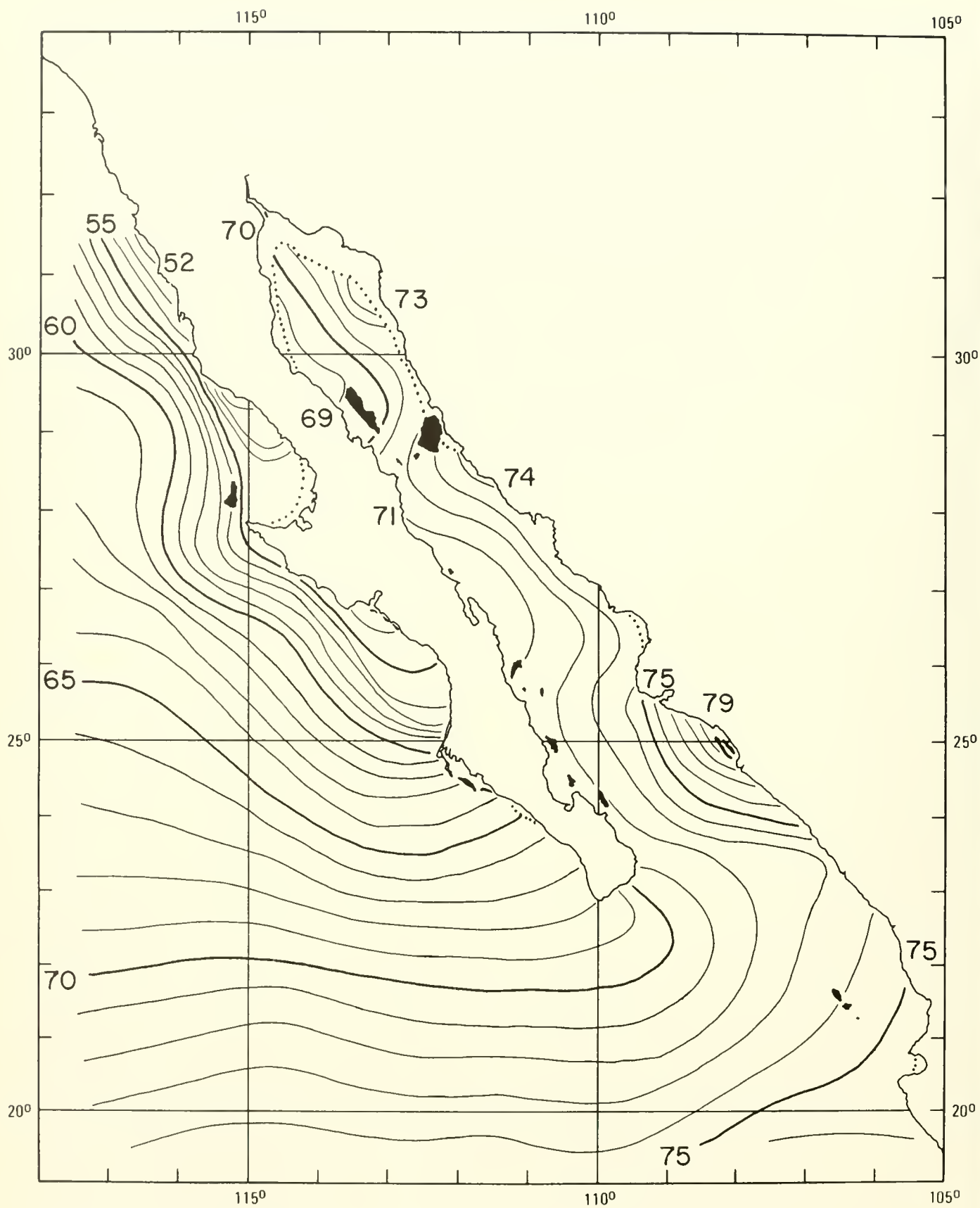


Figure 33. June mean temperatures (°F) at 100 feet.

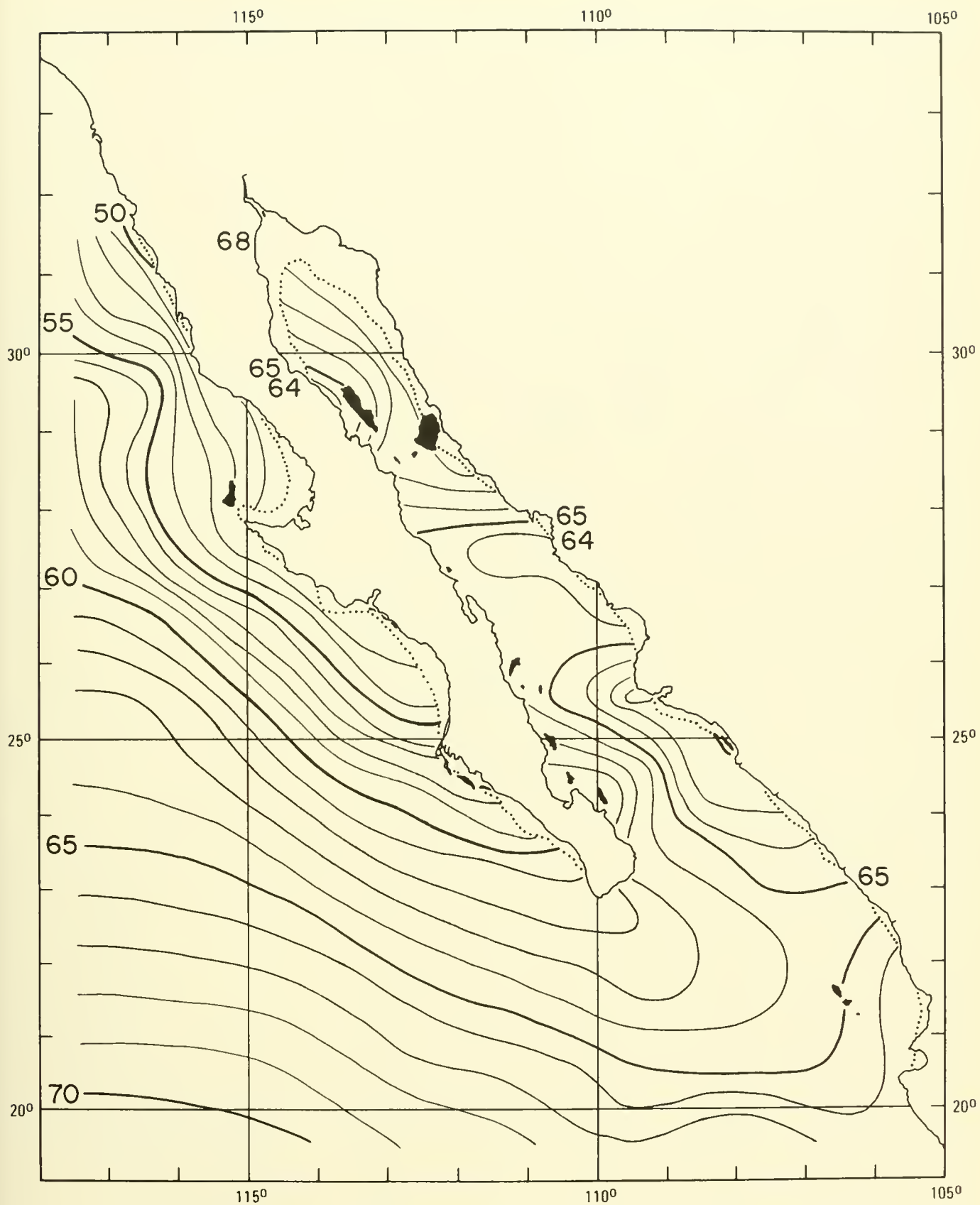


Figure 34. June mean temperatures ($^{\circ}$ F) at 200 feet.

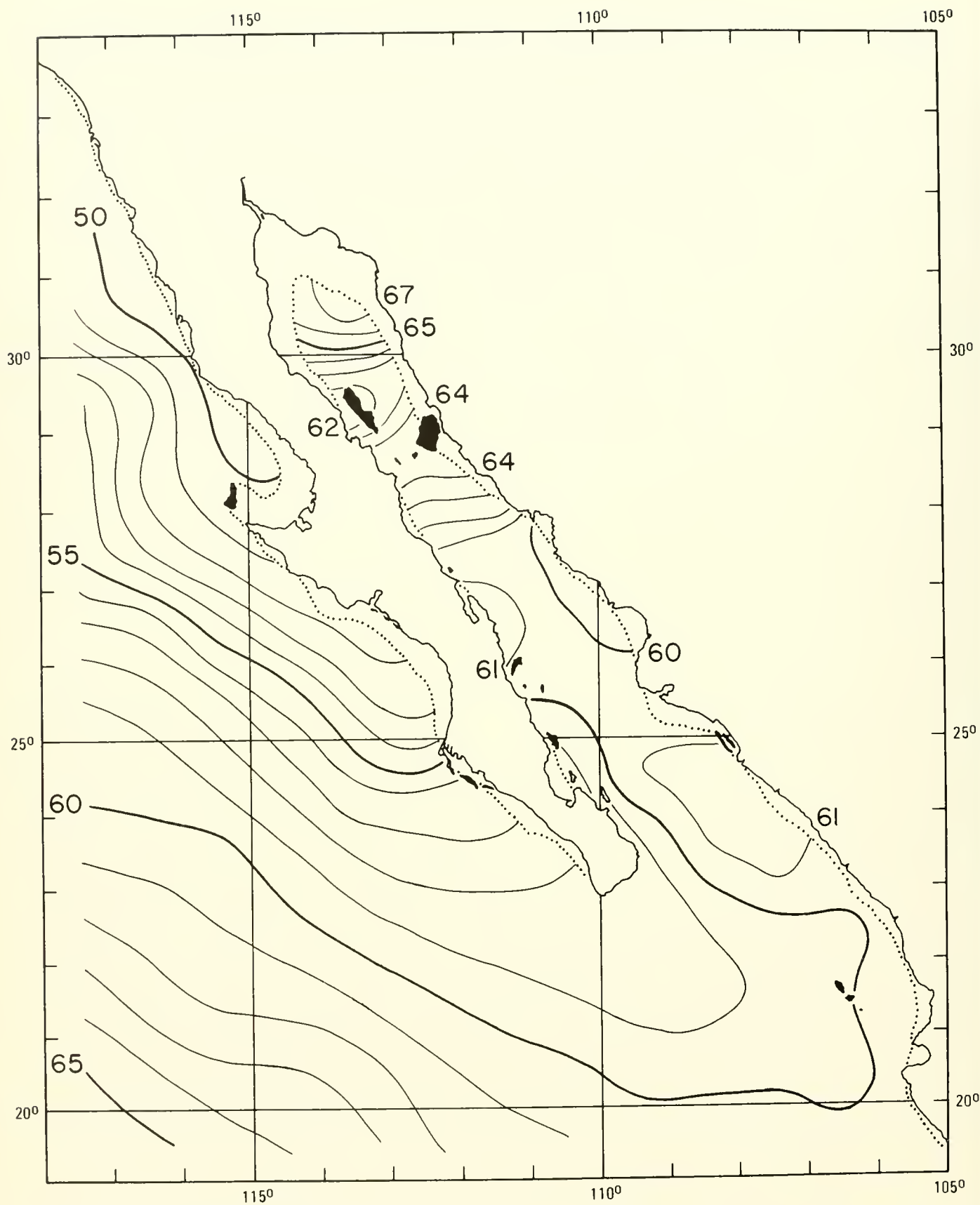


Figure 35. June mean temperatures ($^{\circ}$ F) at 300 feet.

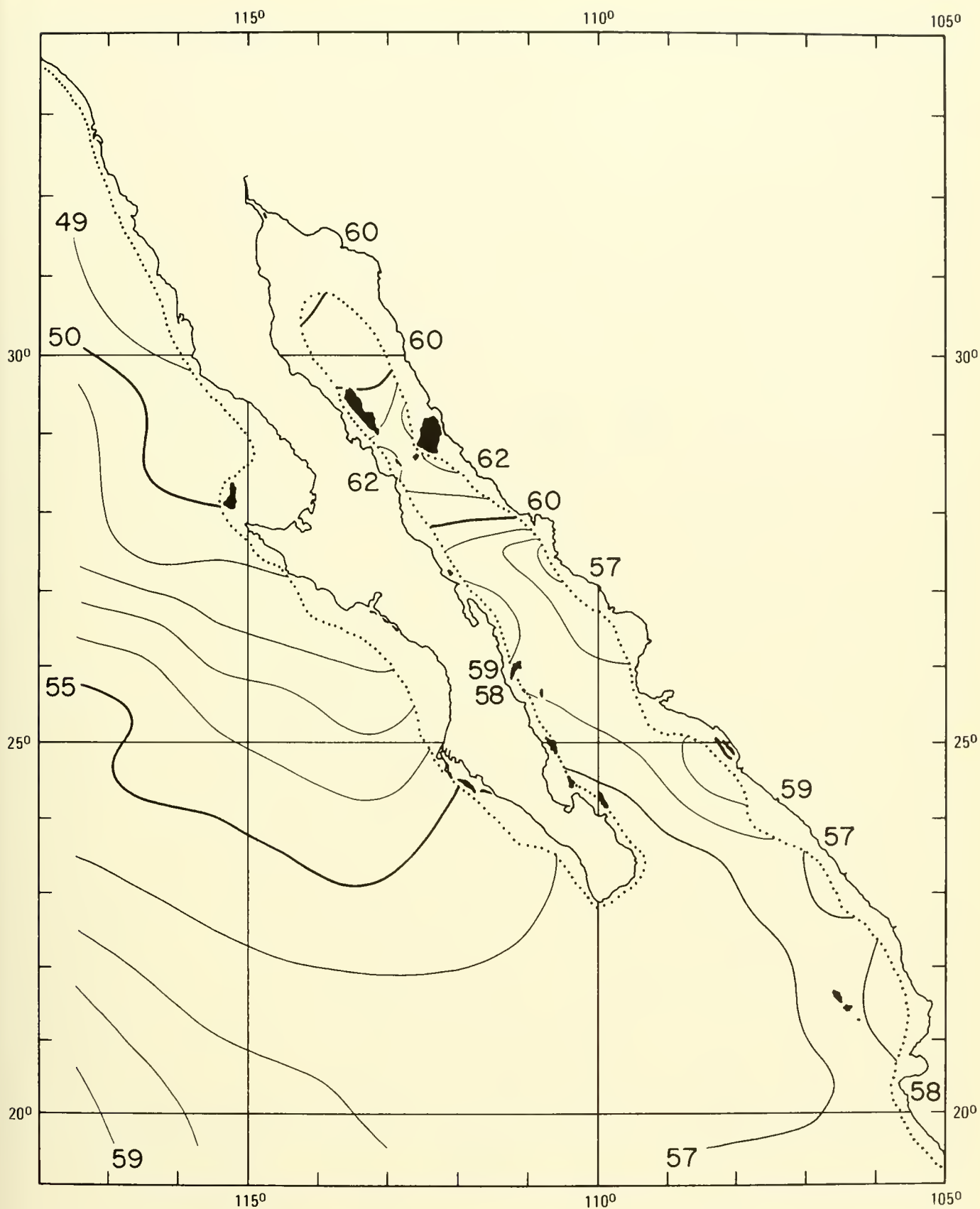


Figure 36. June mean temperatures ($^{\circ}$ F) at 400 feet.

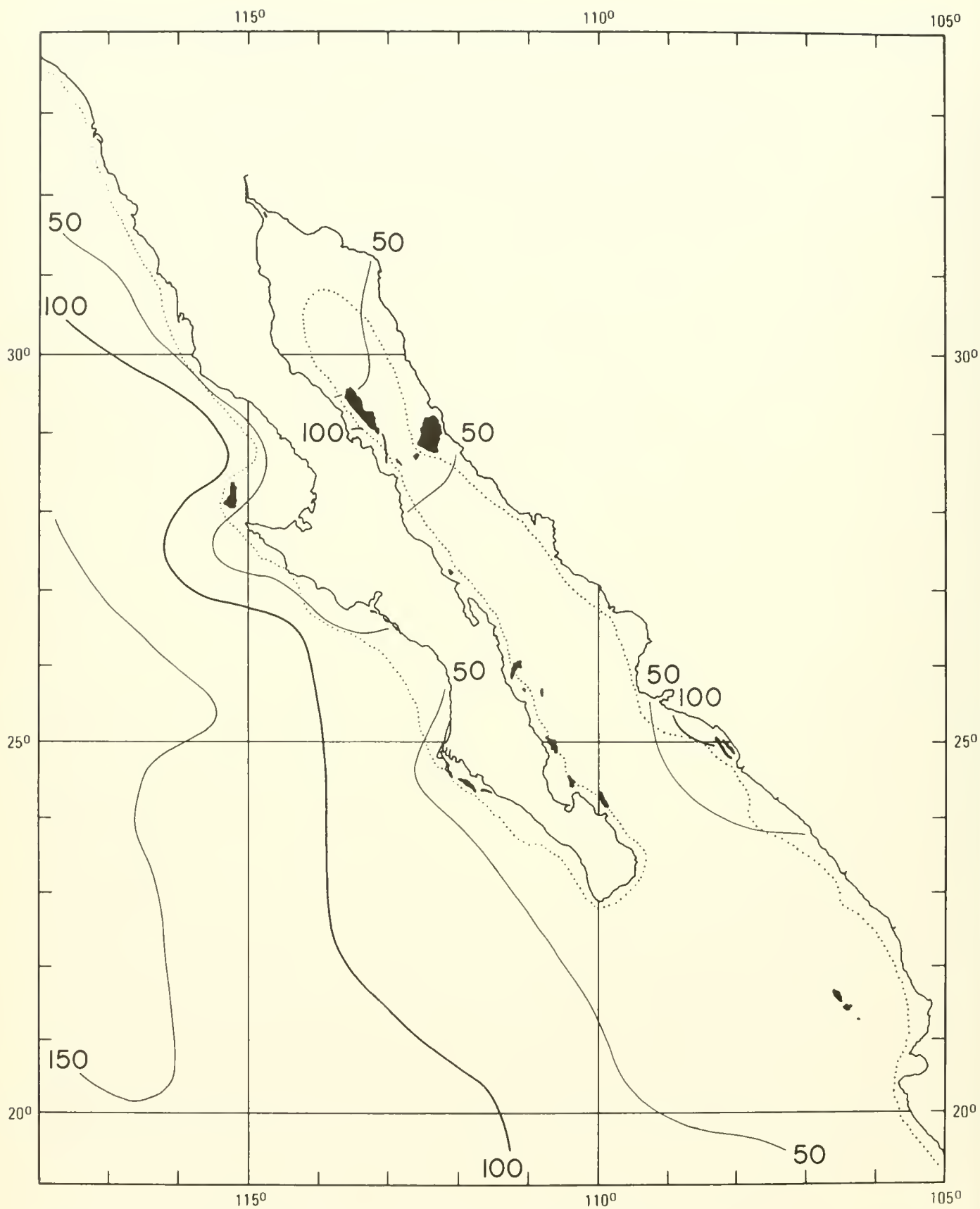


Figure 37. June mean thermocline depth (feet). (See text for definition.)

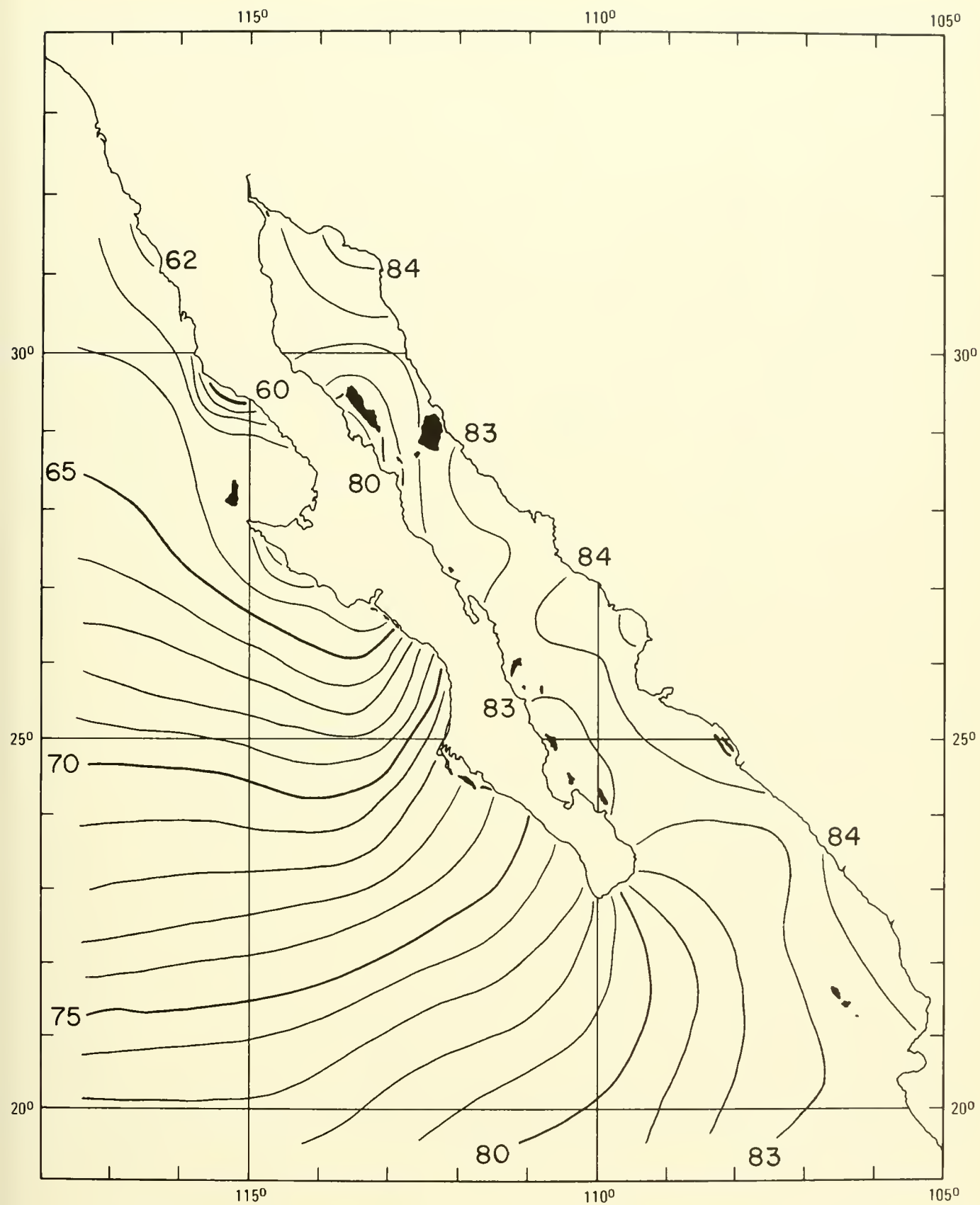


Figure 38. July mean sea surface temperatures (°F).

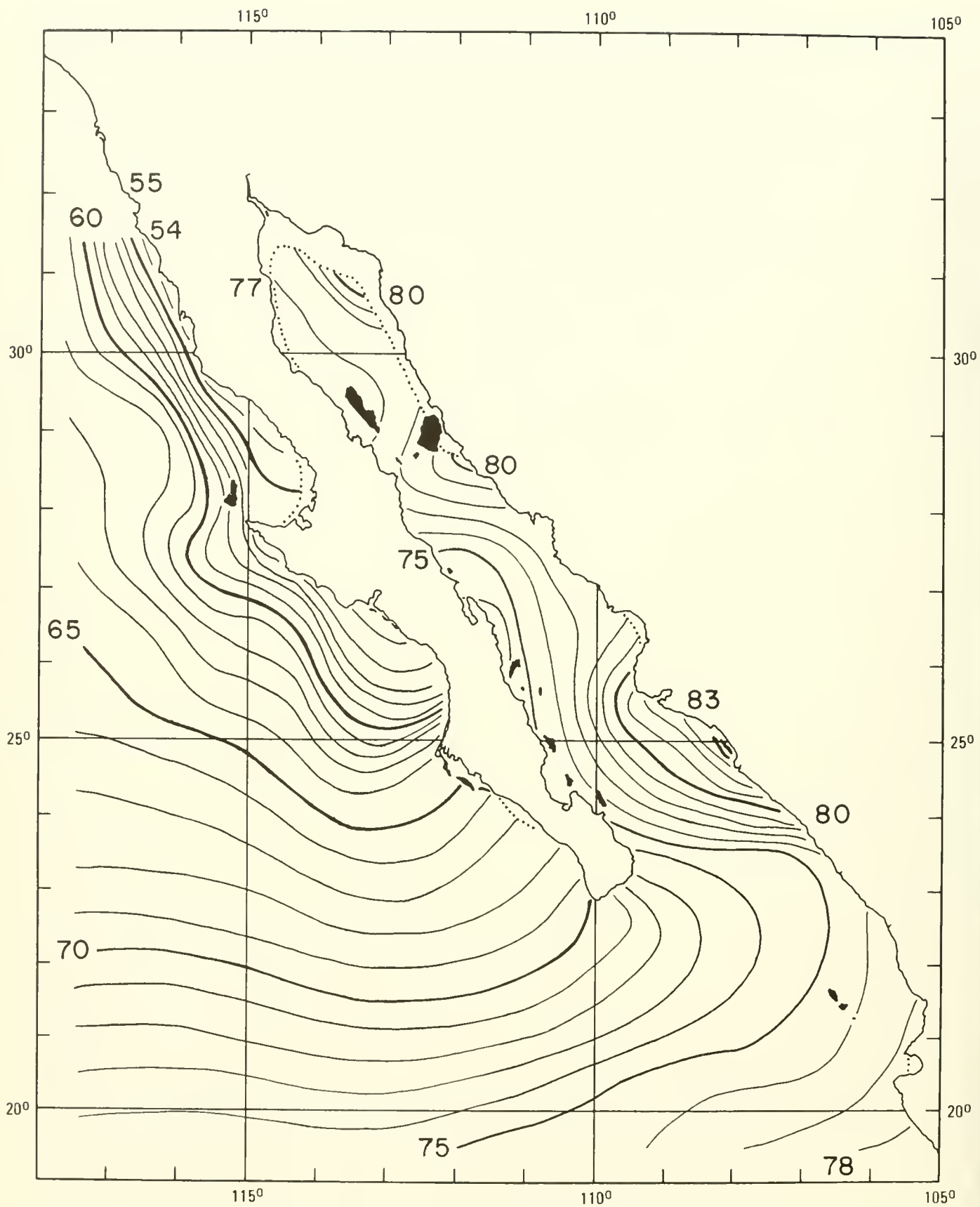


Figure 39. July mean temperatures ($^{\circ}$ F) at 100 feet.

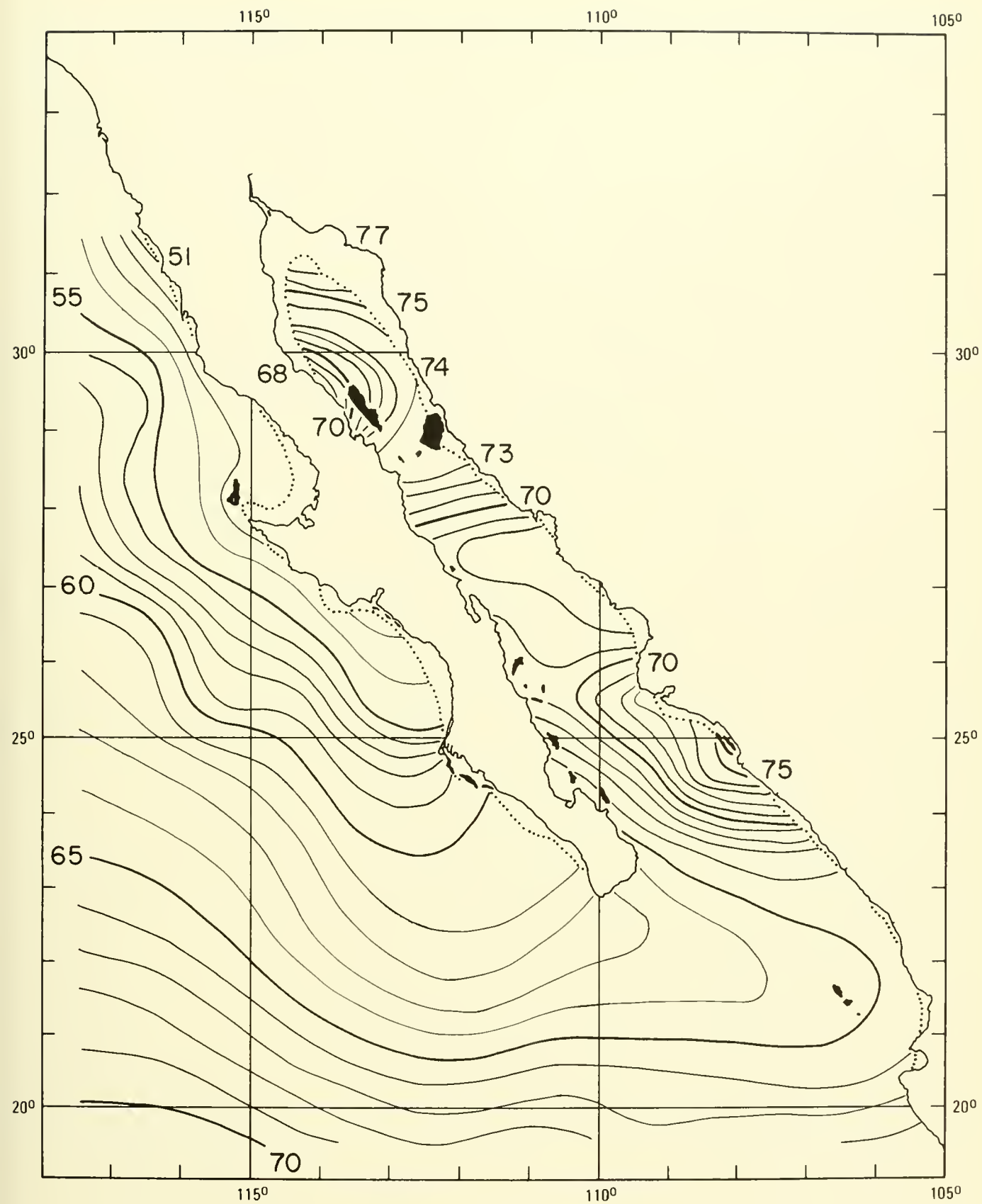


Figure 40. July mean temperatures ($^{\circ}$ F) at 200 feet.

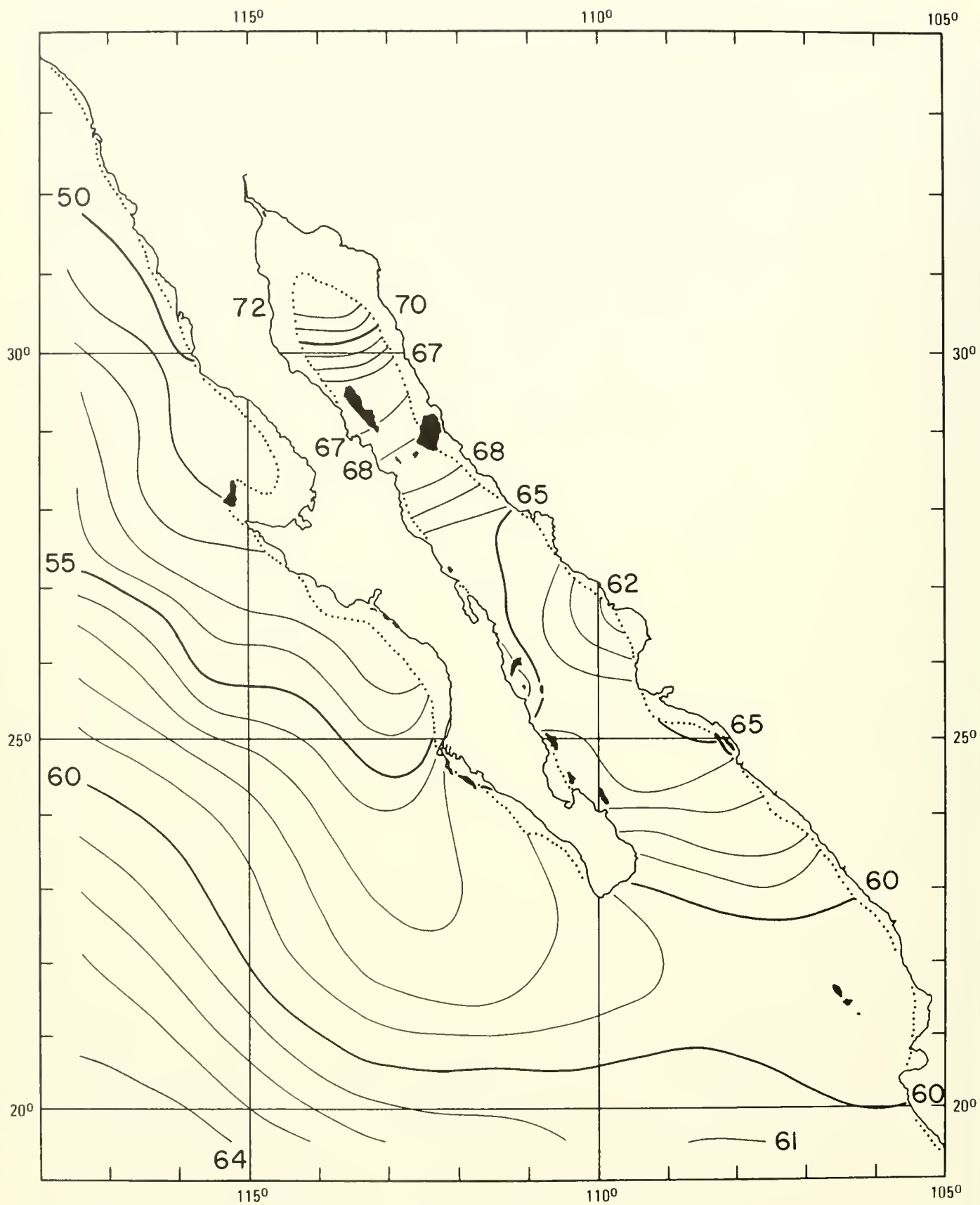


Figure 41. July mean temperatures (°F) at 300 feet.

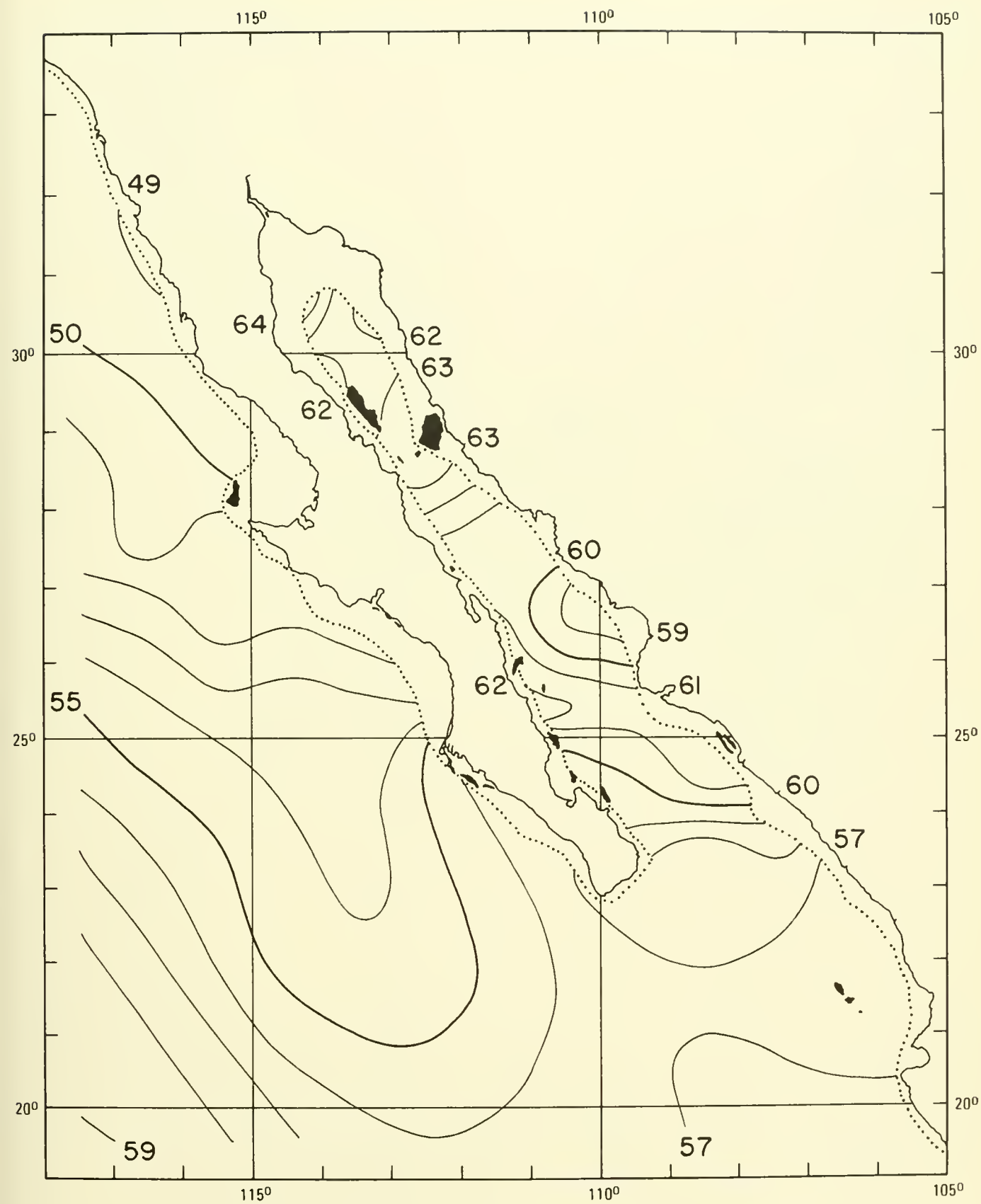


Figure 42. July mean temperatures ($^{\circ}$ F) at 400 feet.

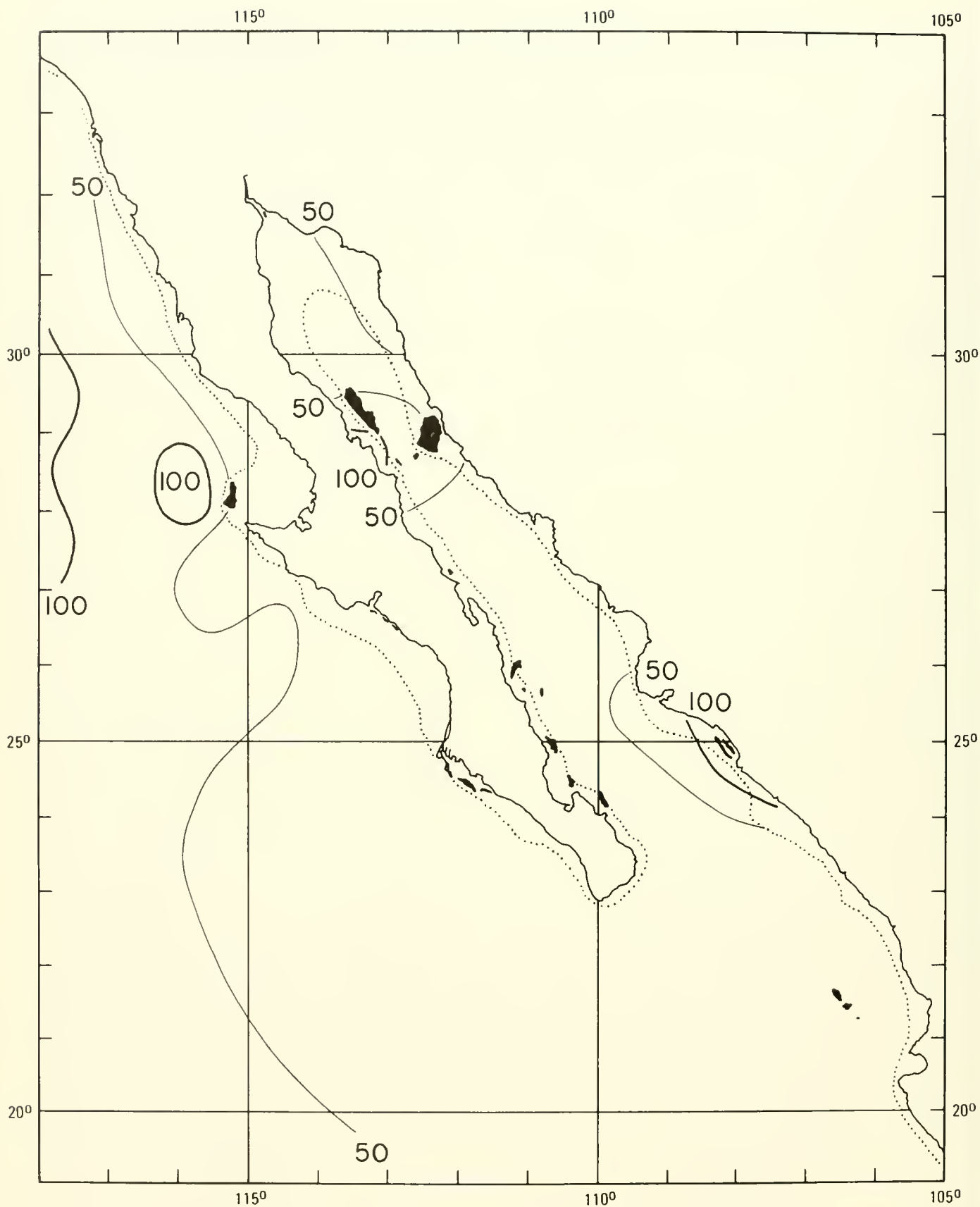


Figure 43. July mean thermocline depth (feet). (See text for definition.)

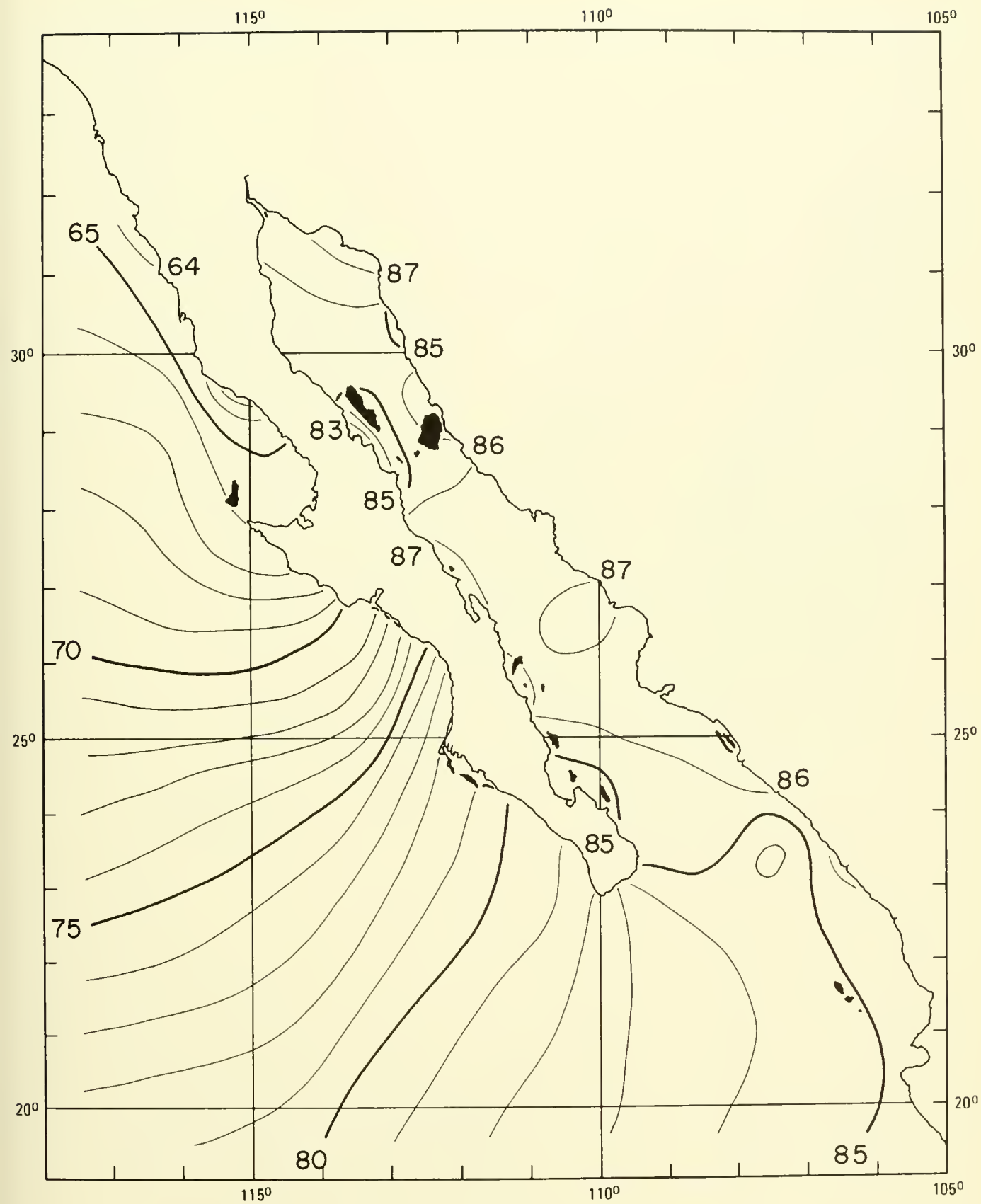


Figure 44. August mean sea surface temperatures (°F).

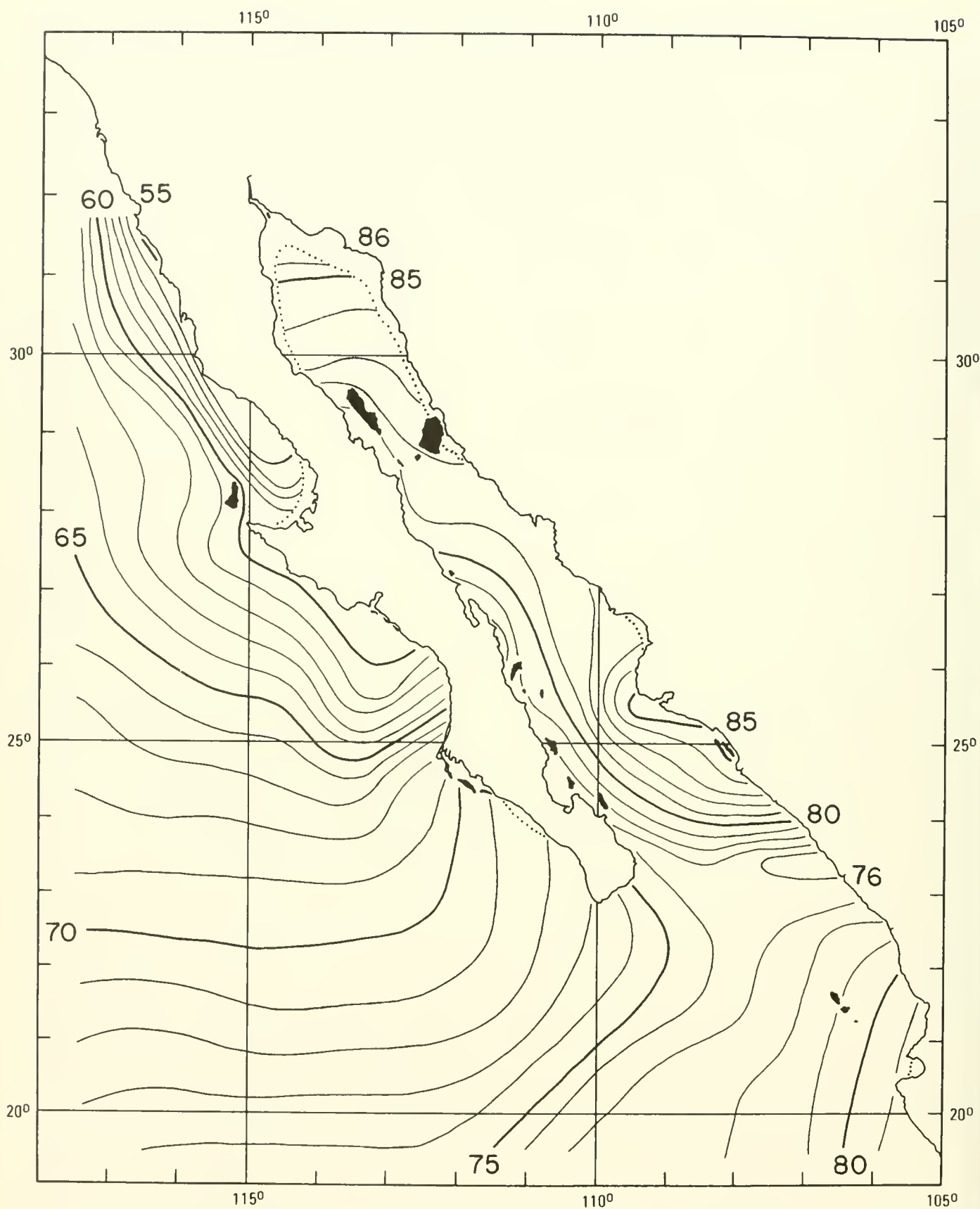


Figure 45. August mean temperatures ($^{\circ}$ F) at 100 feet.

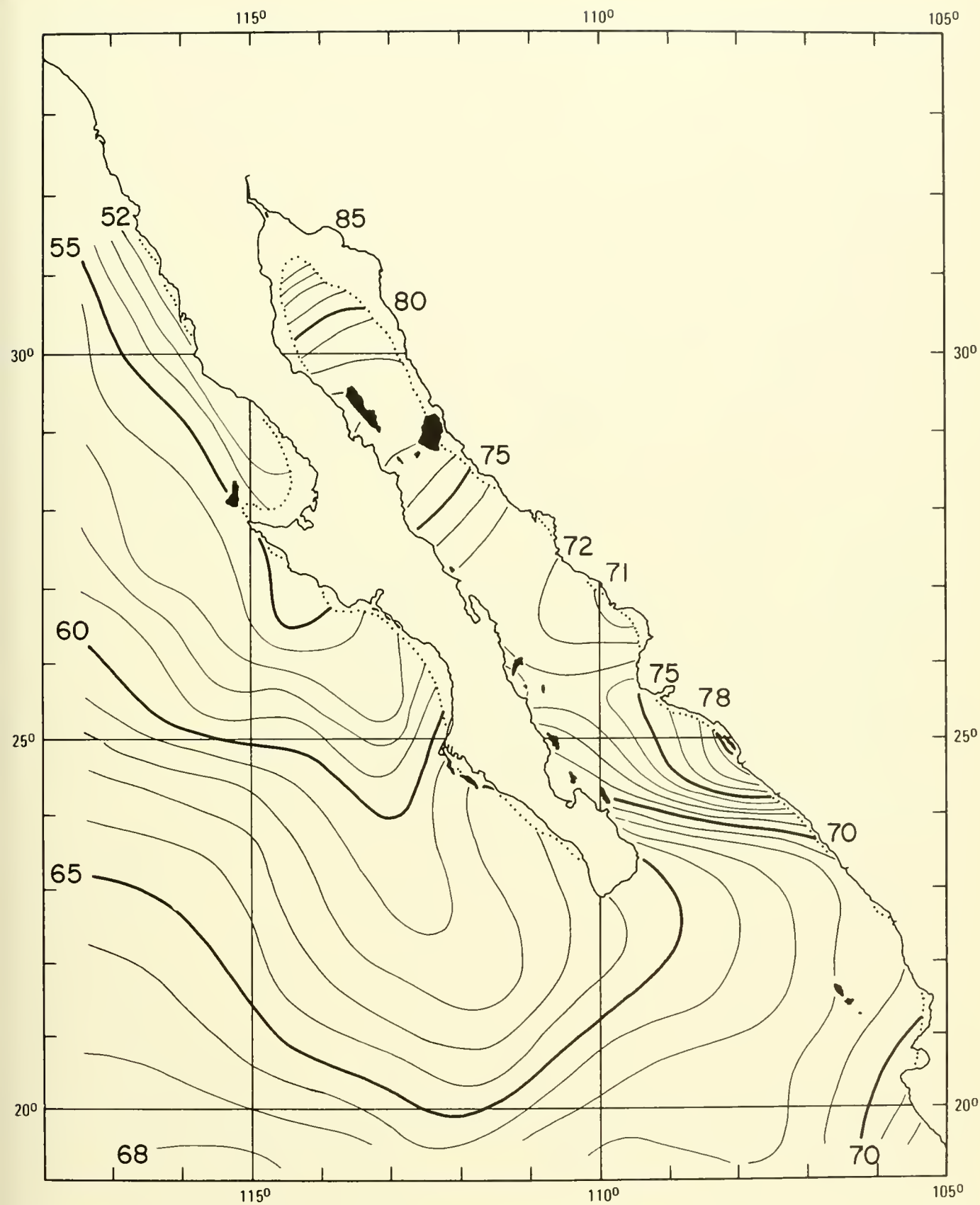


Figure 46. August mean temperatures ($^{\circ}$ F) at 200 feet.

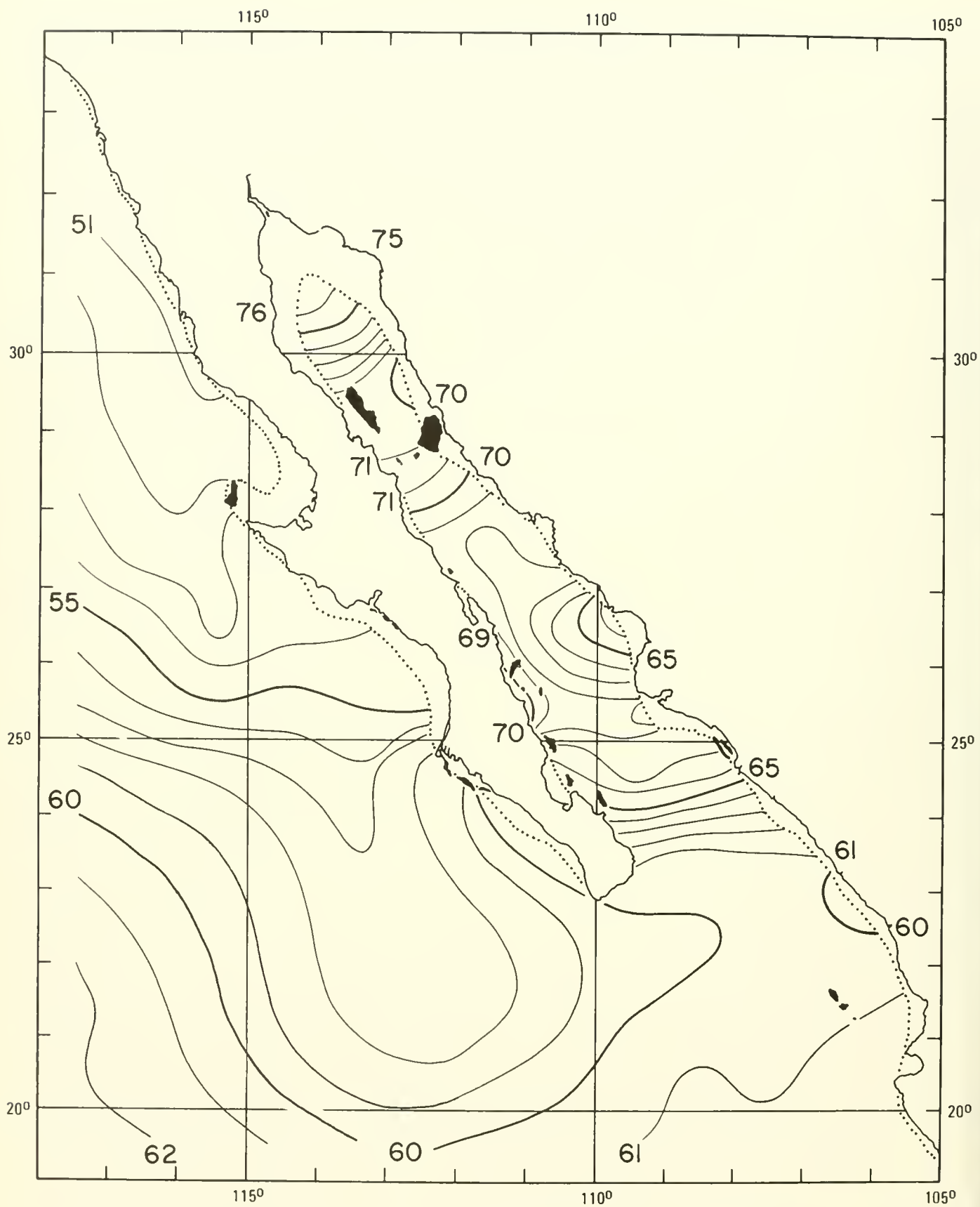


Figure 47. August mean temperatures ($^{\circ}$ F) at 300 feet.

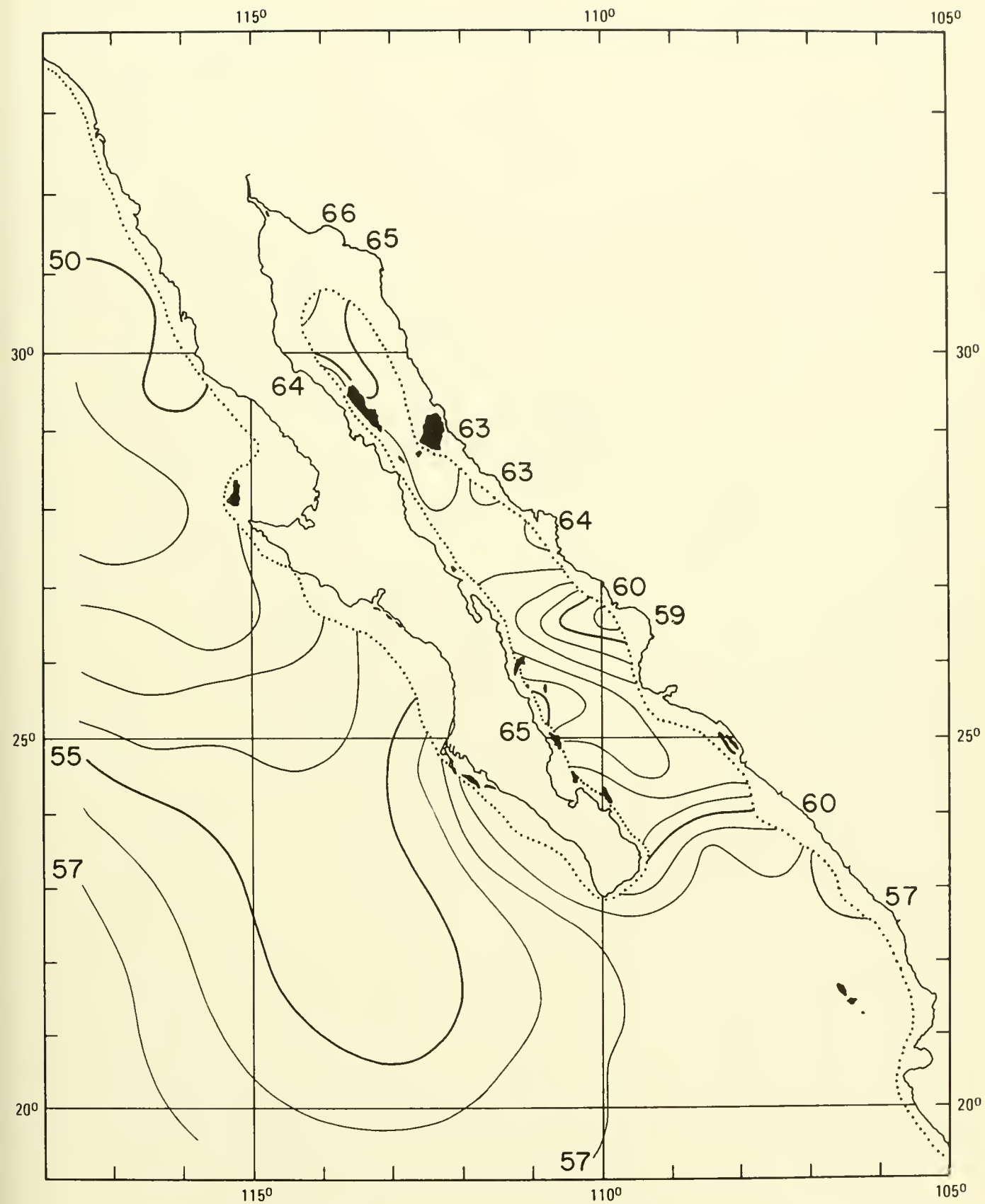


Figure 48. August mean temperatures ($^{\circ}$ F) at 400 feet.

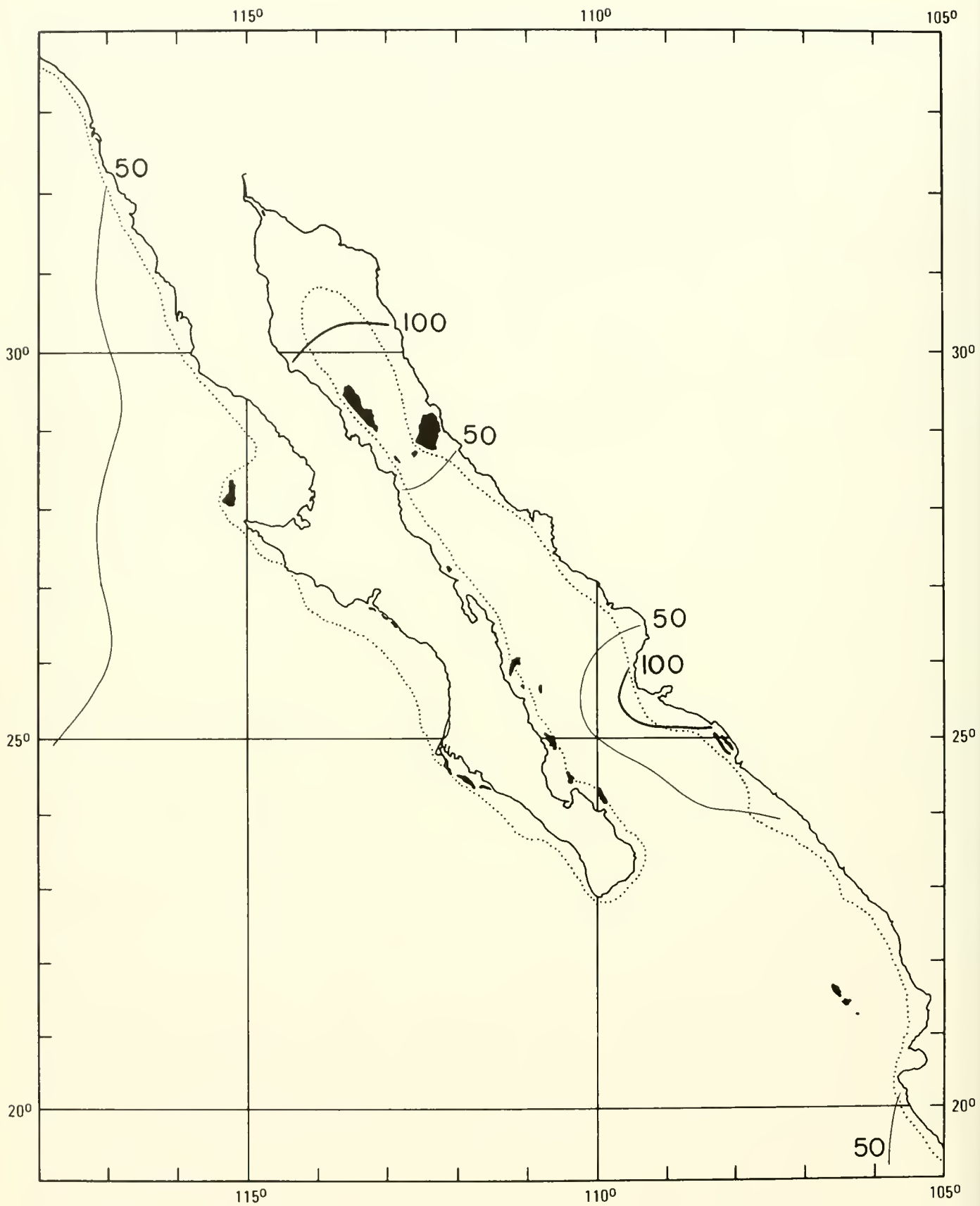


Figure 49. August mean thermocline depth (feet). (See text for definition.)

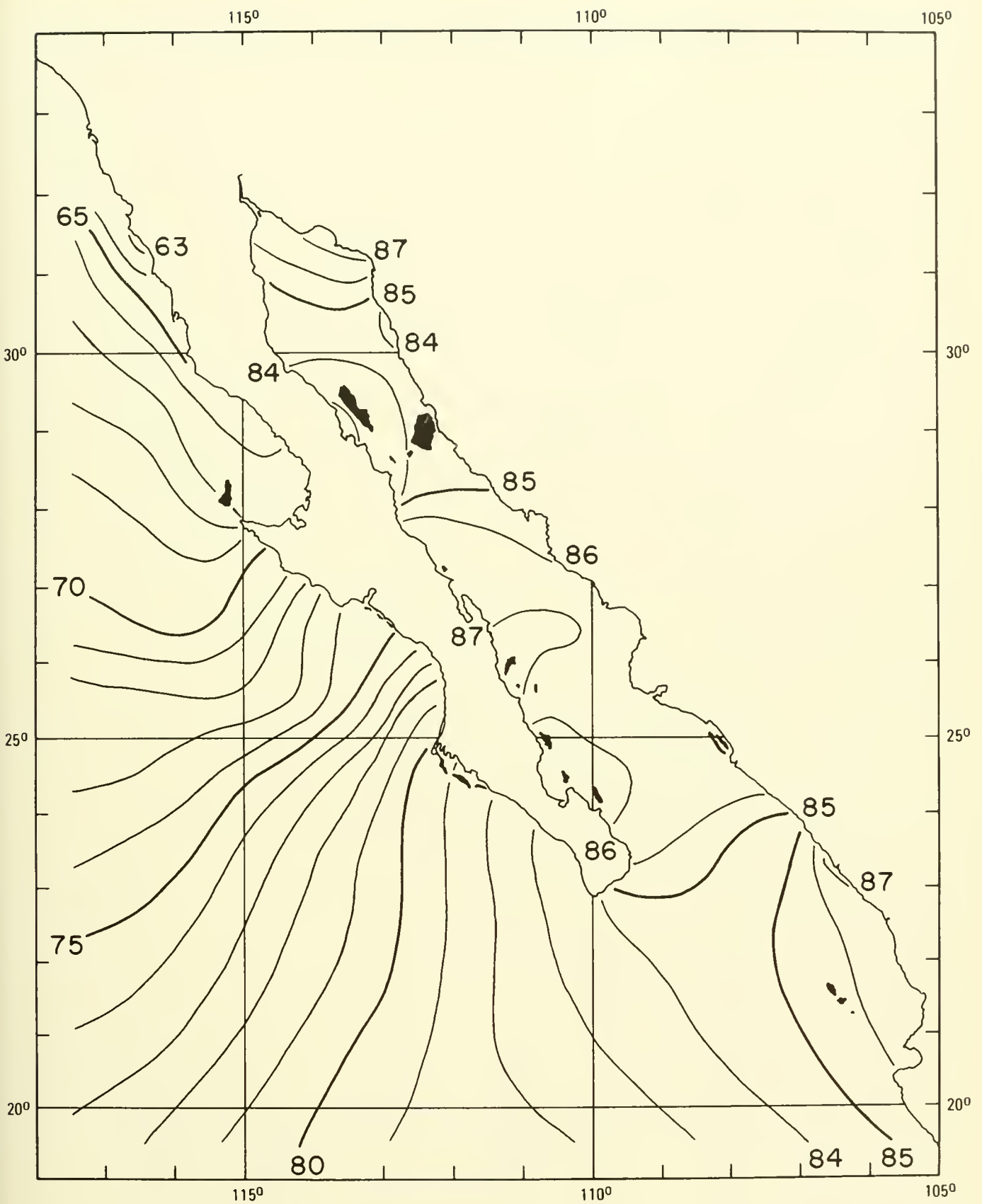


Figure 50. September mean sea surface temperatures (°F).

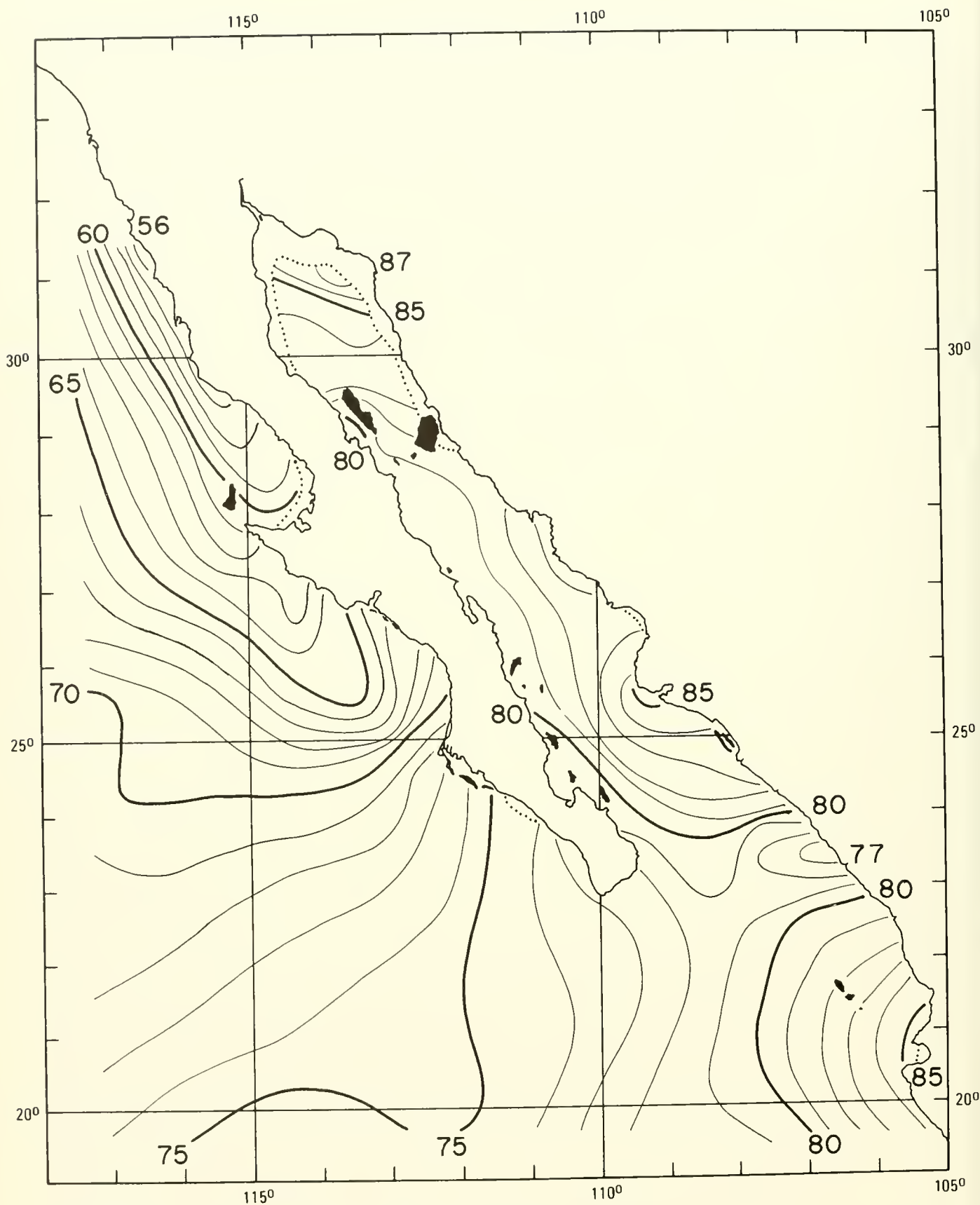


Figure 51. September mean temperatures ($^{\circ}$ F) at 100 feet.

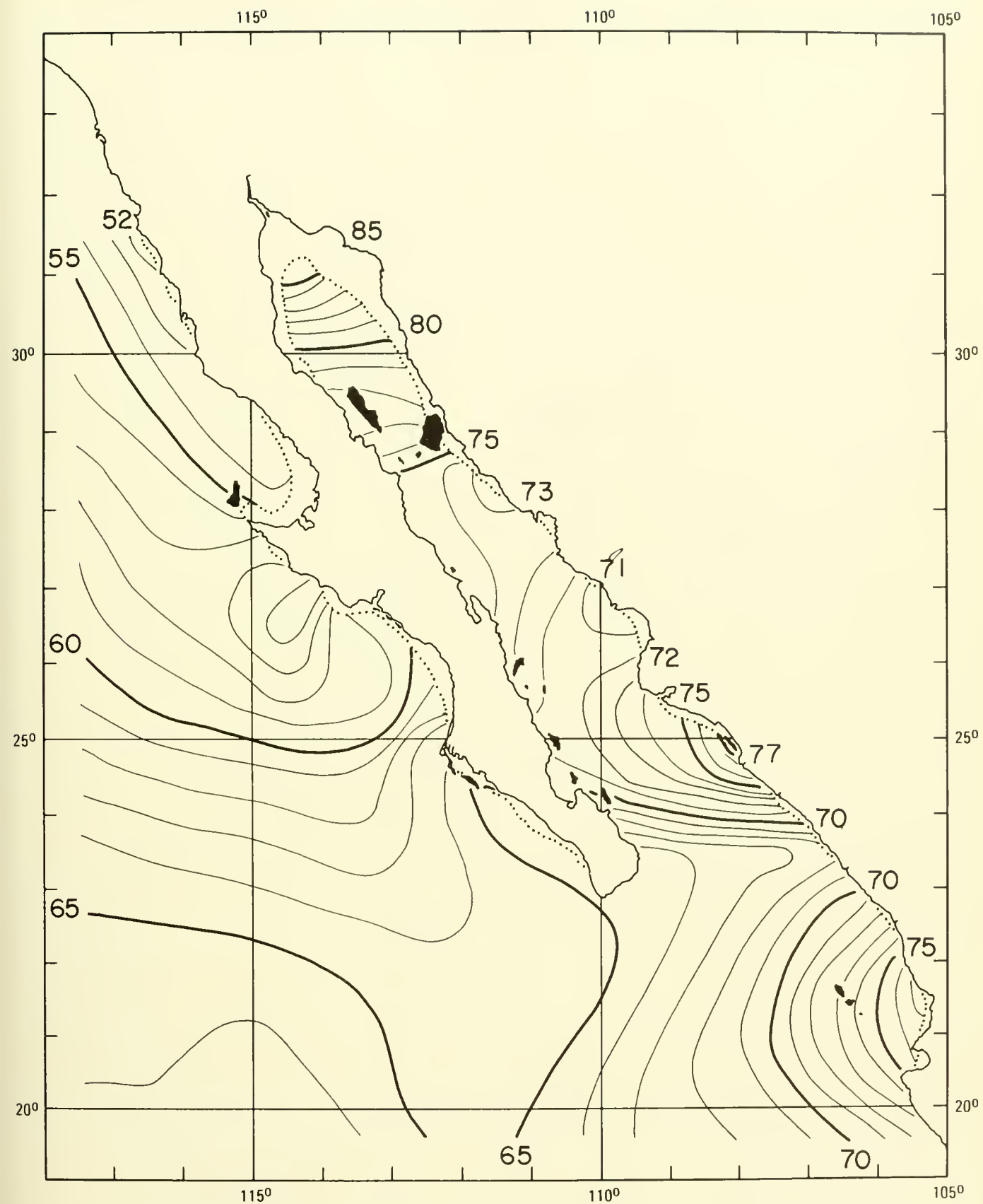


Figure 52. September mean temperatures ($^{\circ}$ F) at 200 feet.

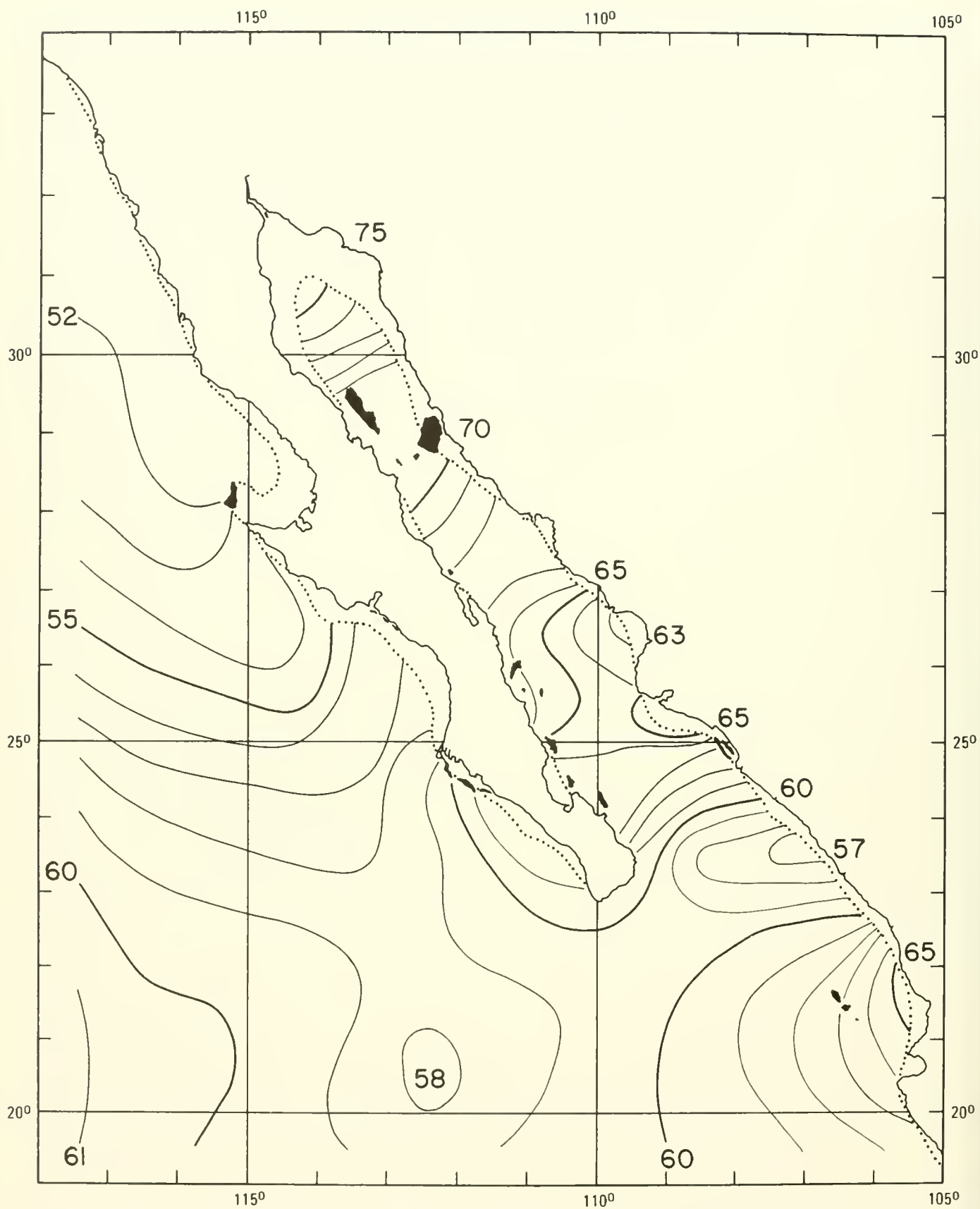


Figure 53. September mean temperatures ($^{\circ}$ F) at 300 feet.

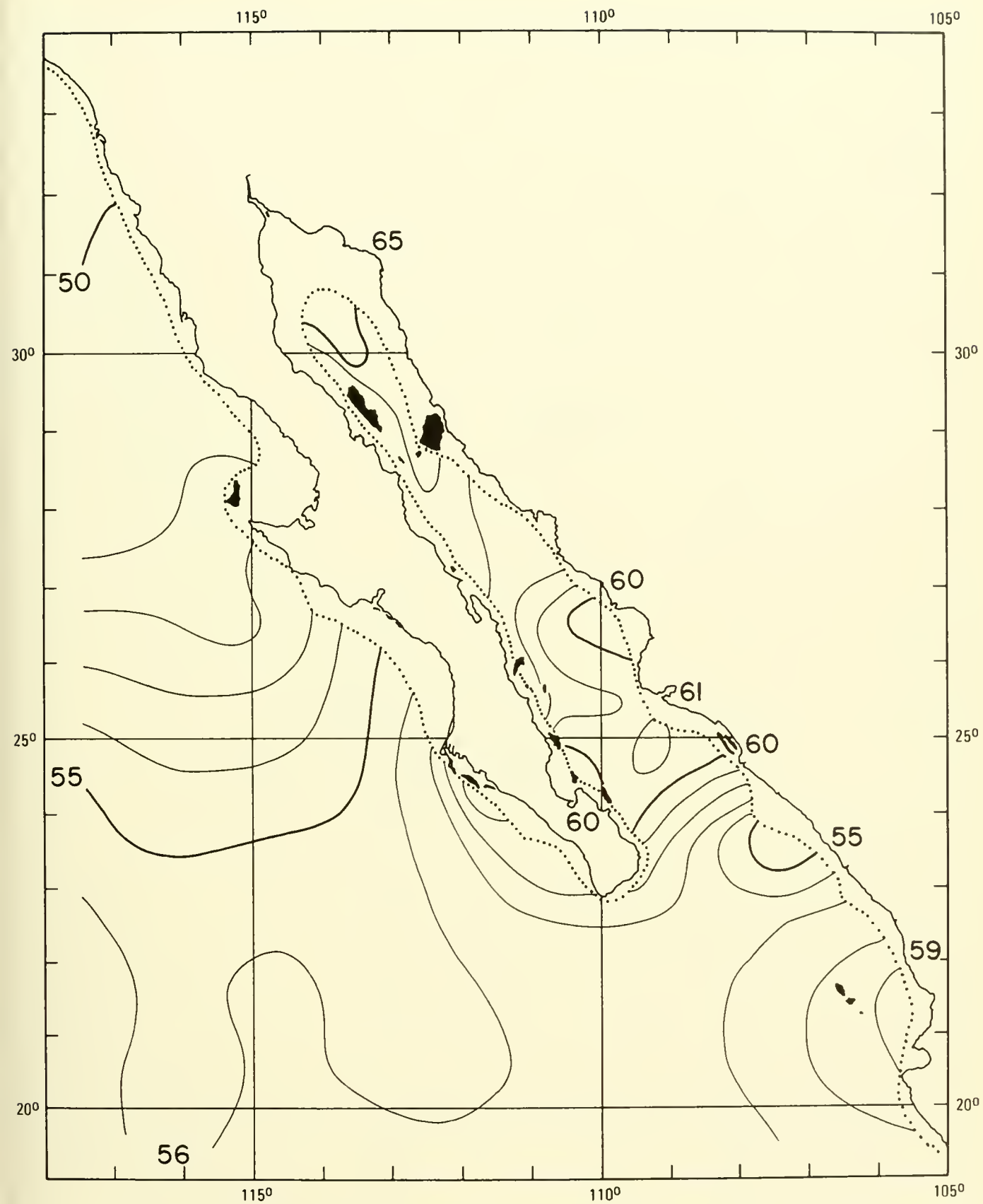


Figure 54. September mean temperatures ($^{\circ}$ F) at 400 feet.

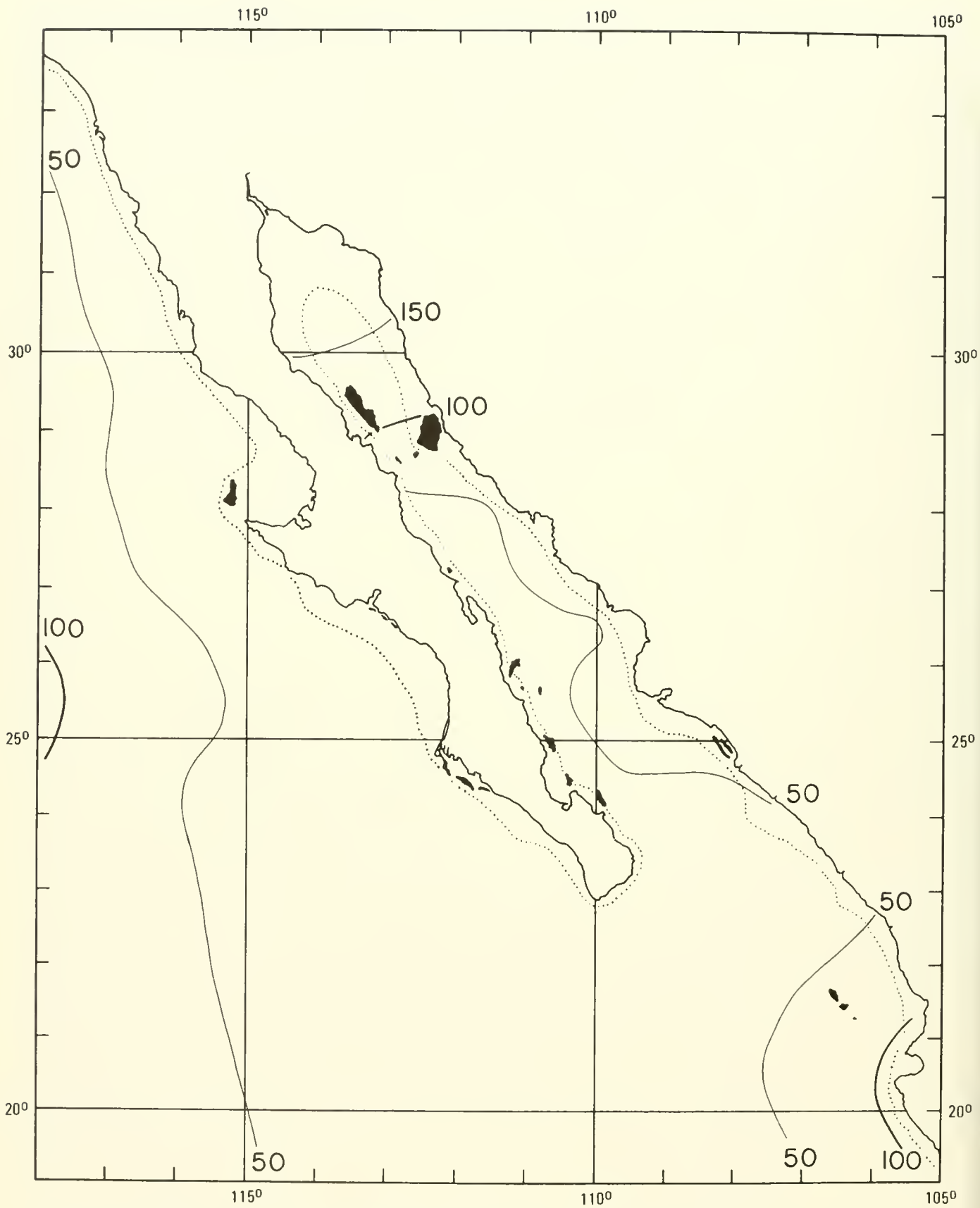


Figure 55. September mean thermocline depth (feet). (See text for definition.)

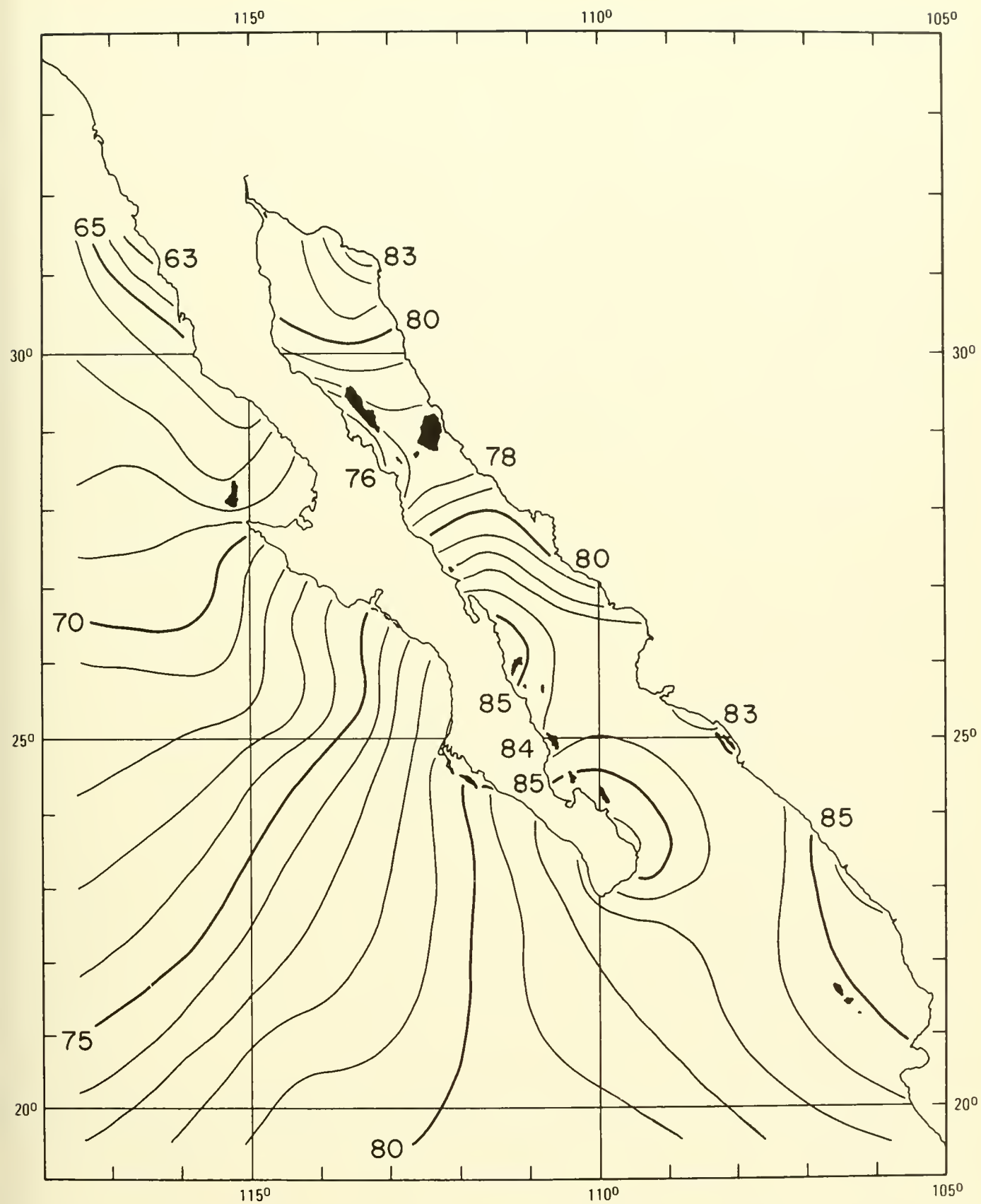


Figure 56. October mean sea surface temperatures (°F).

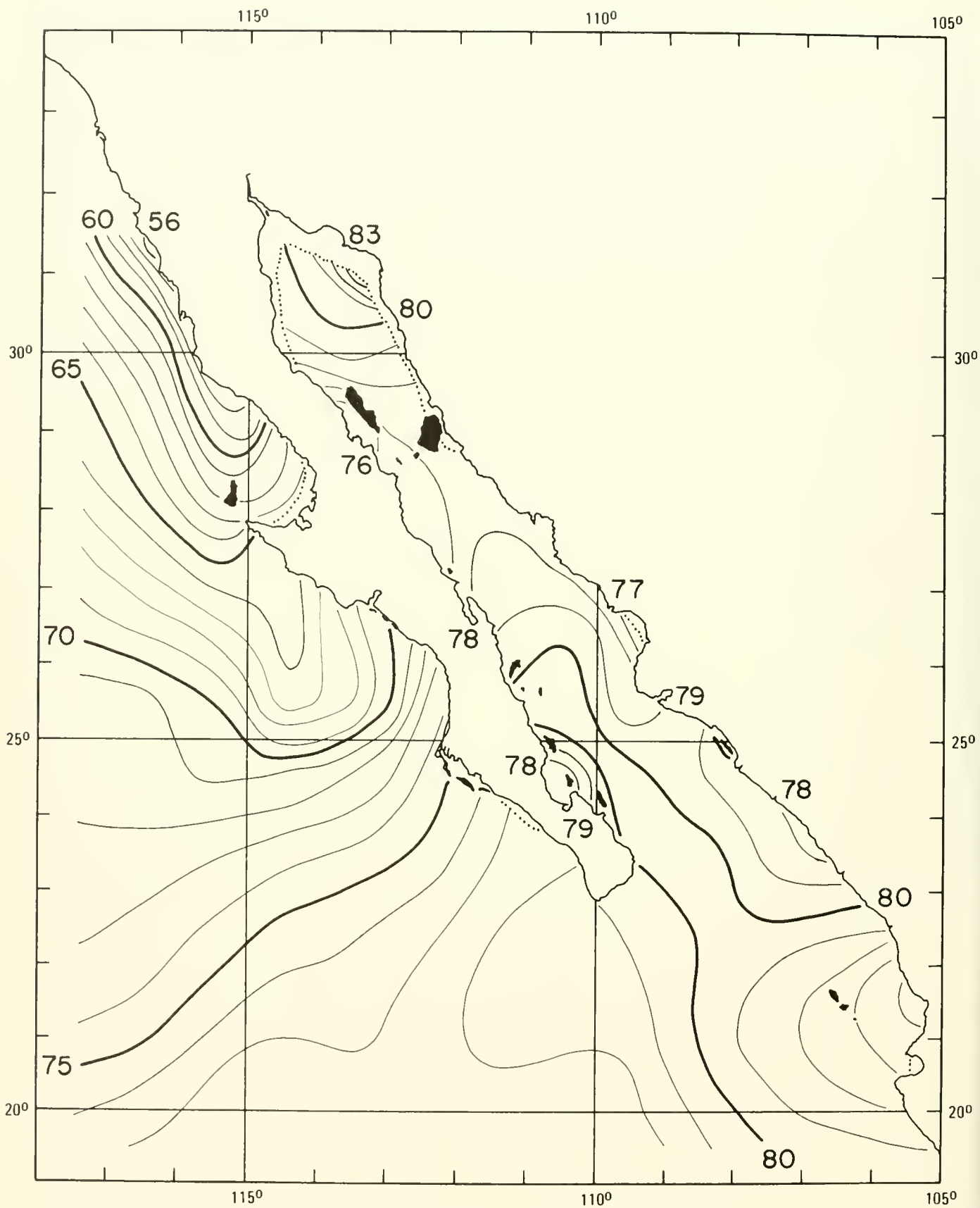


Figure 57. October mean temperatures ($^{\circ}$ F) at 100 feet.

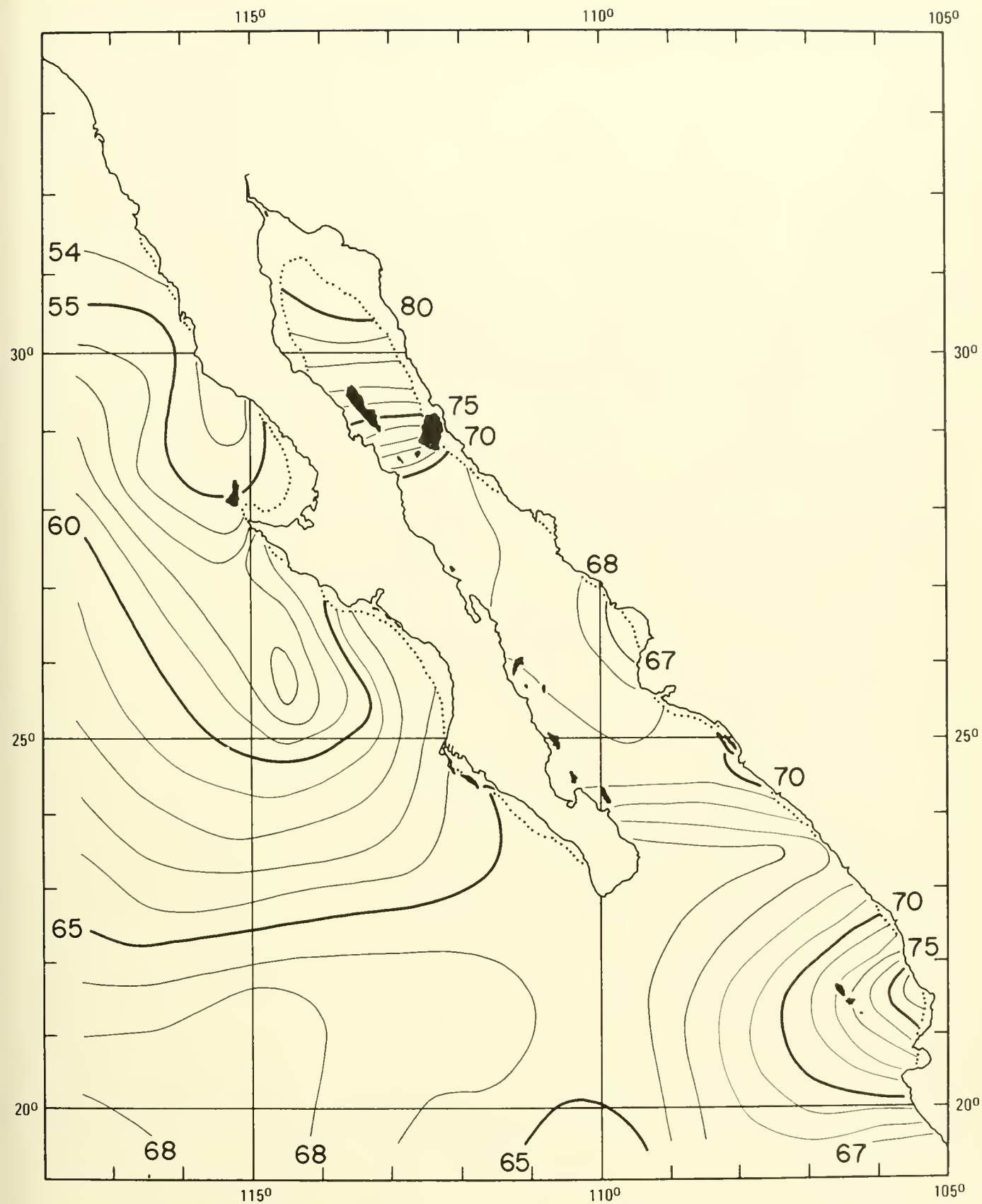


Figure 58. October mean temperatures ($^{\circ}$ F) at 200 feet.

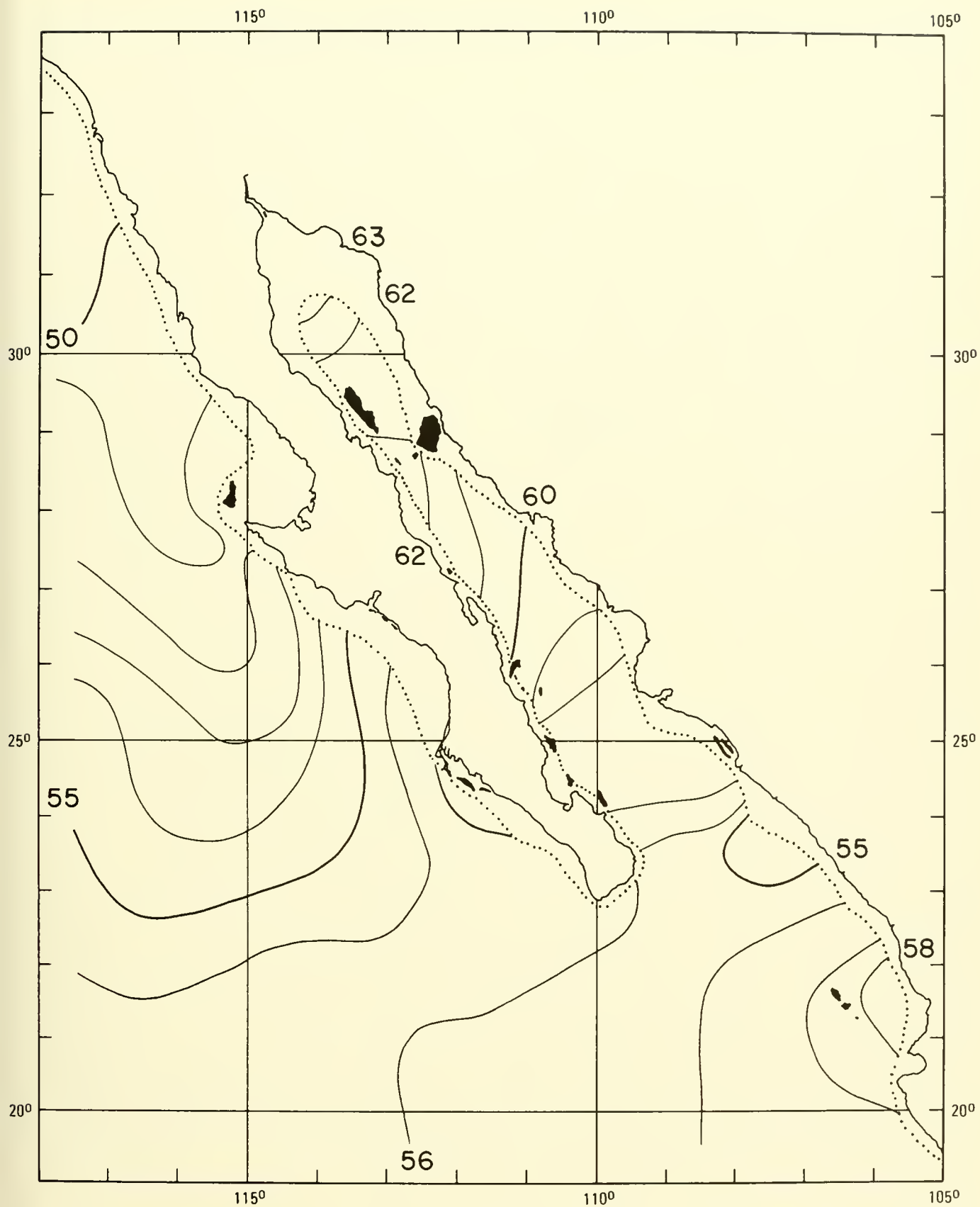


Figure 60. October mean temperatures ($^{\circ}$ F) at 400 feet.

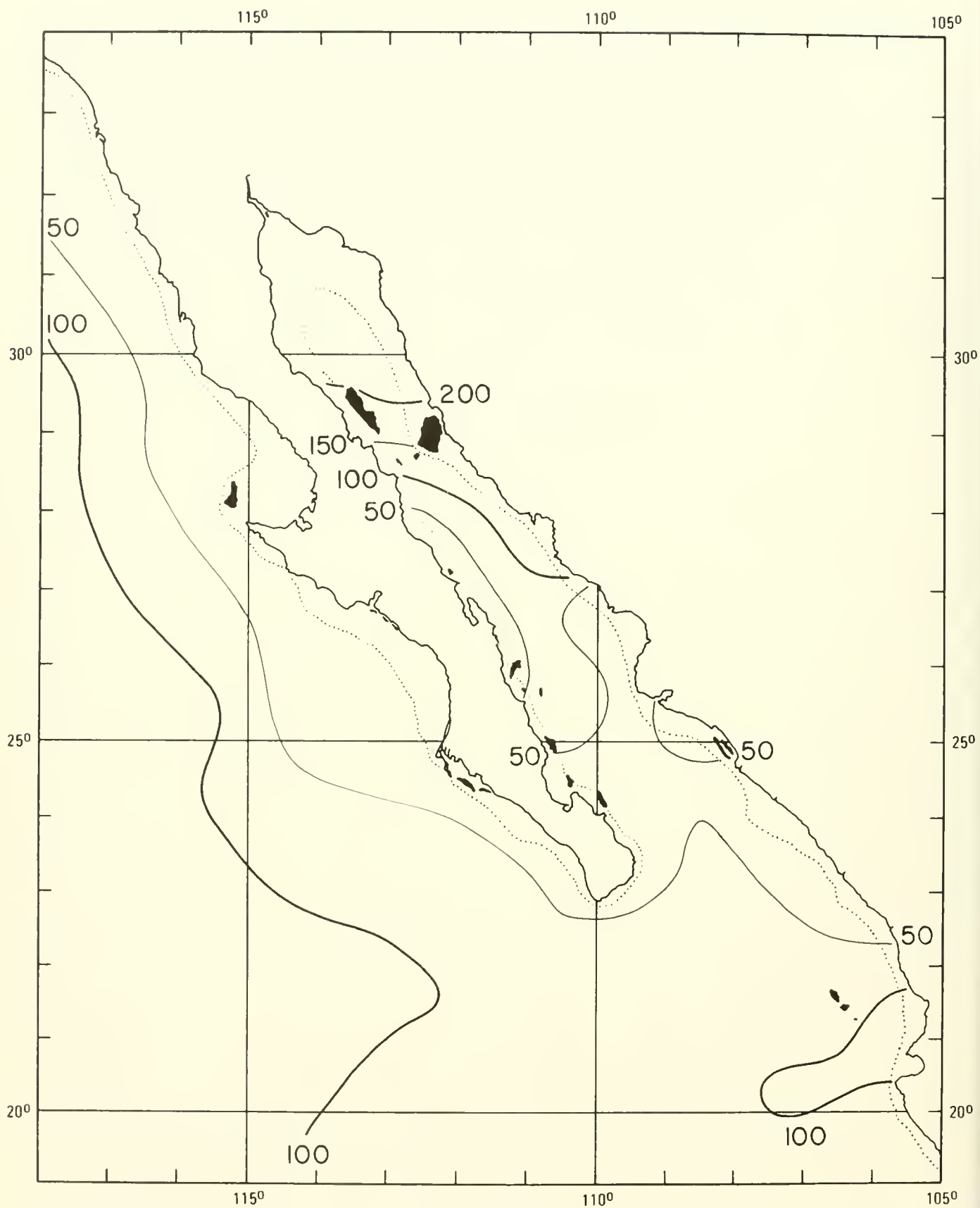


Figure 61. October mean thermocline depth (feet). (See text for definition.)

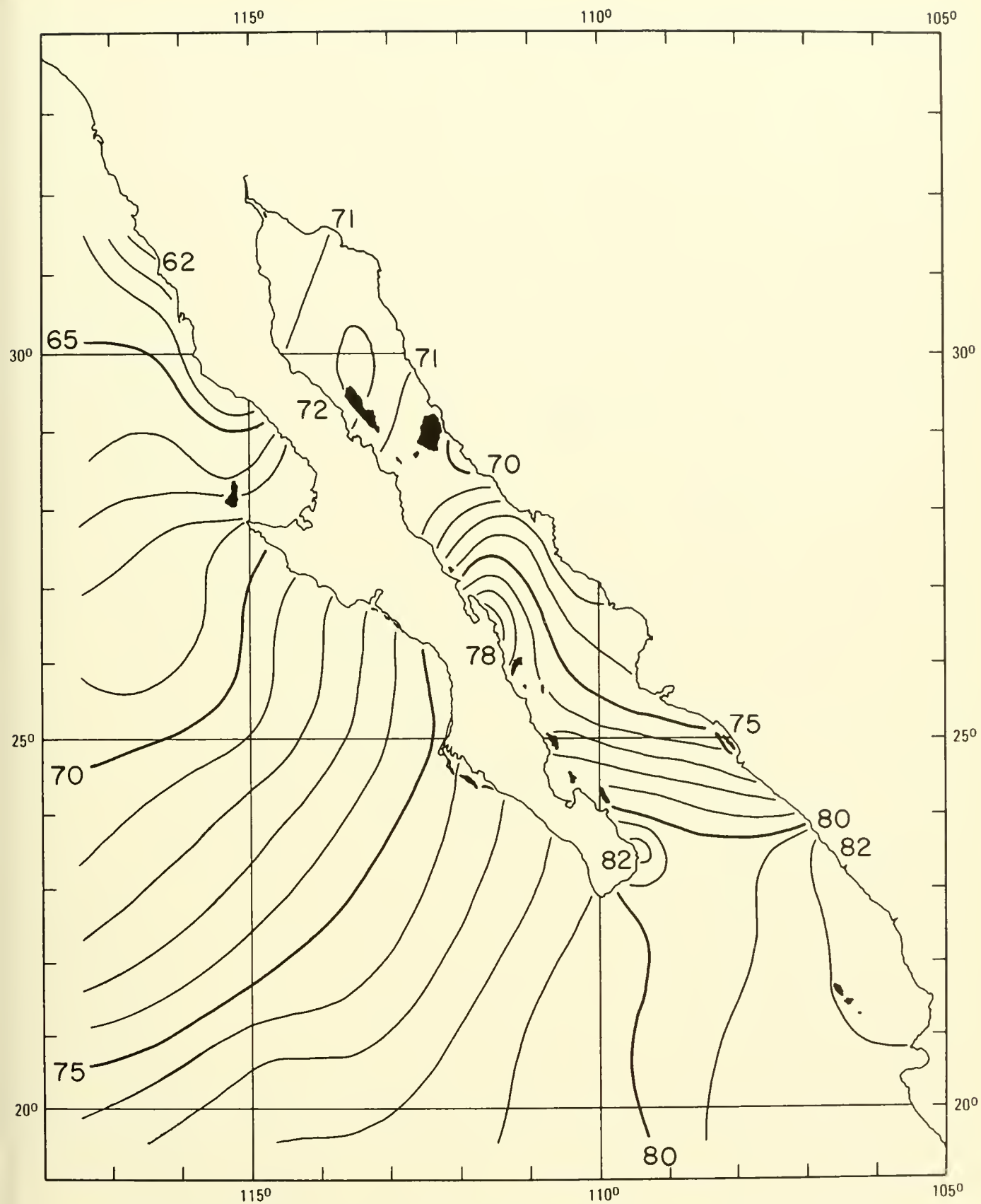


Figure 62. November mean sea surface temperatures (°F).

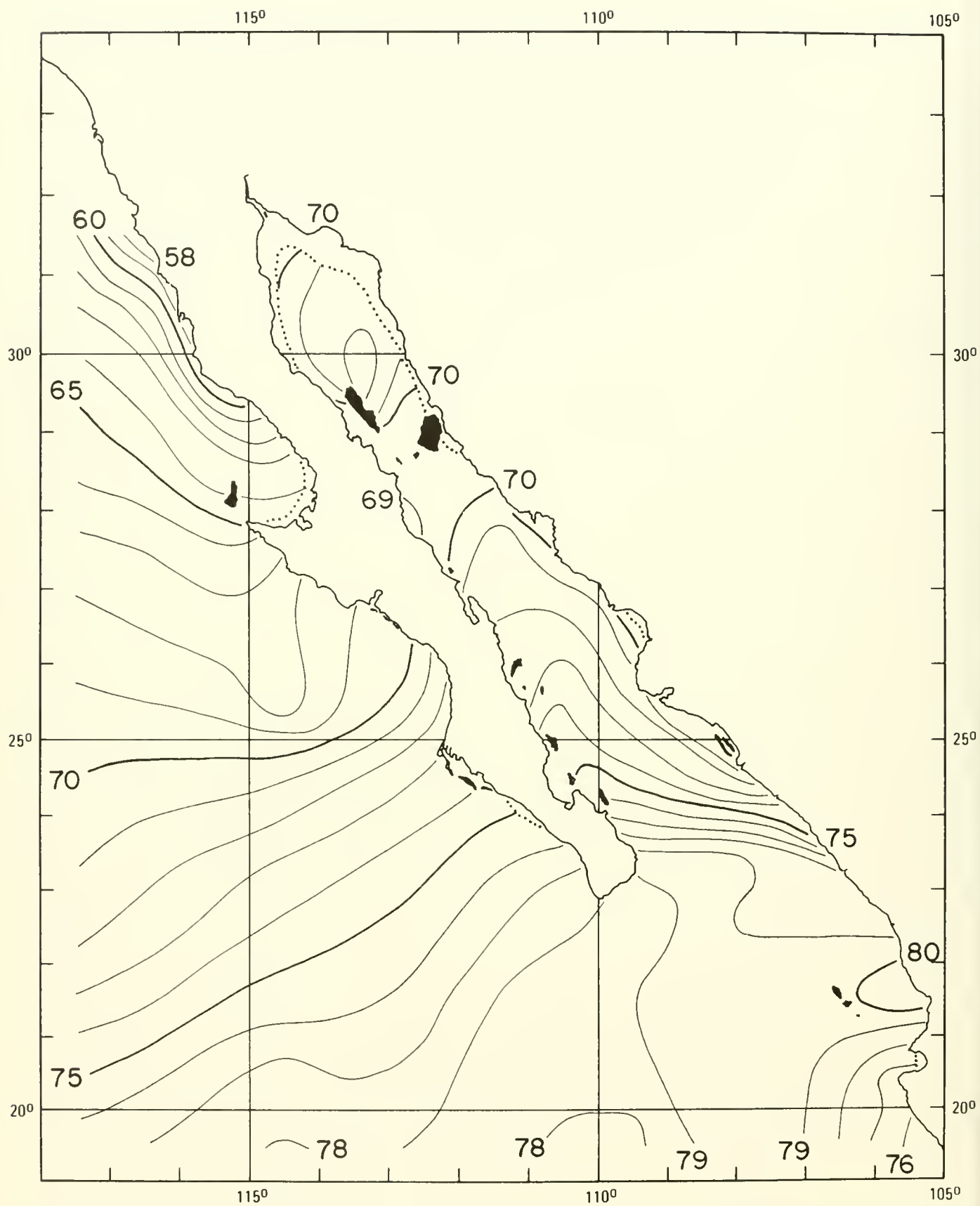


Figure 63. November mean temperatures ($^{\circ}$ F) at 100 feet.

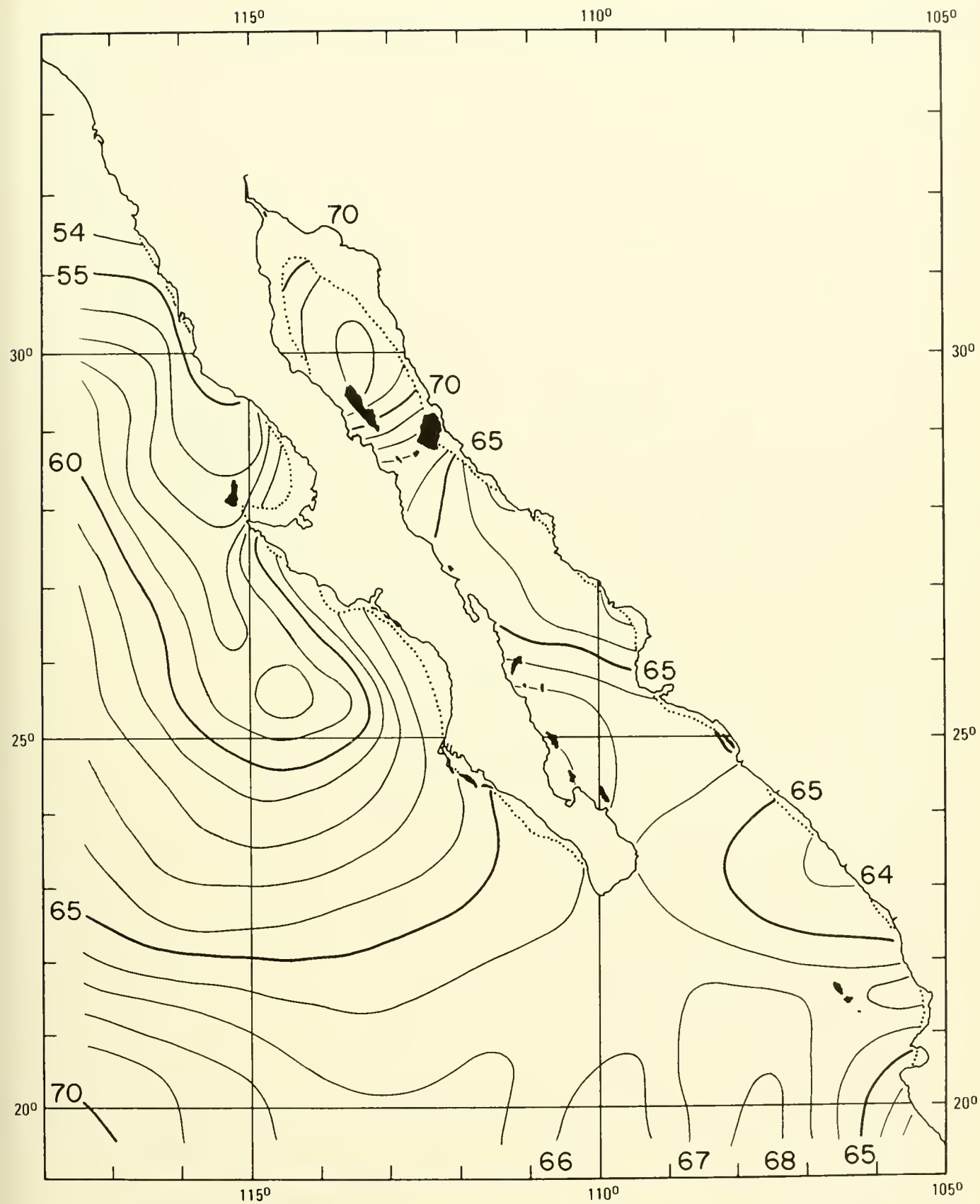


Figure 64. November mean temperatures ($^{\circ}$ F) at 200 feet.

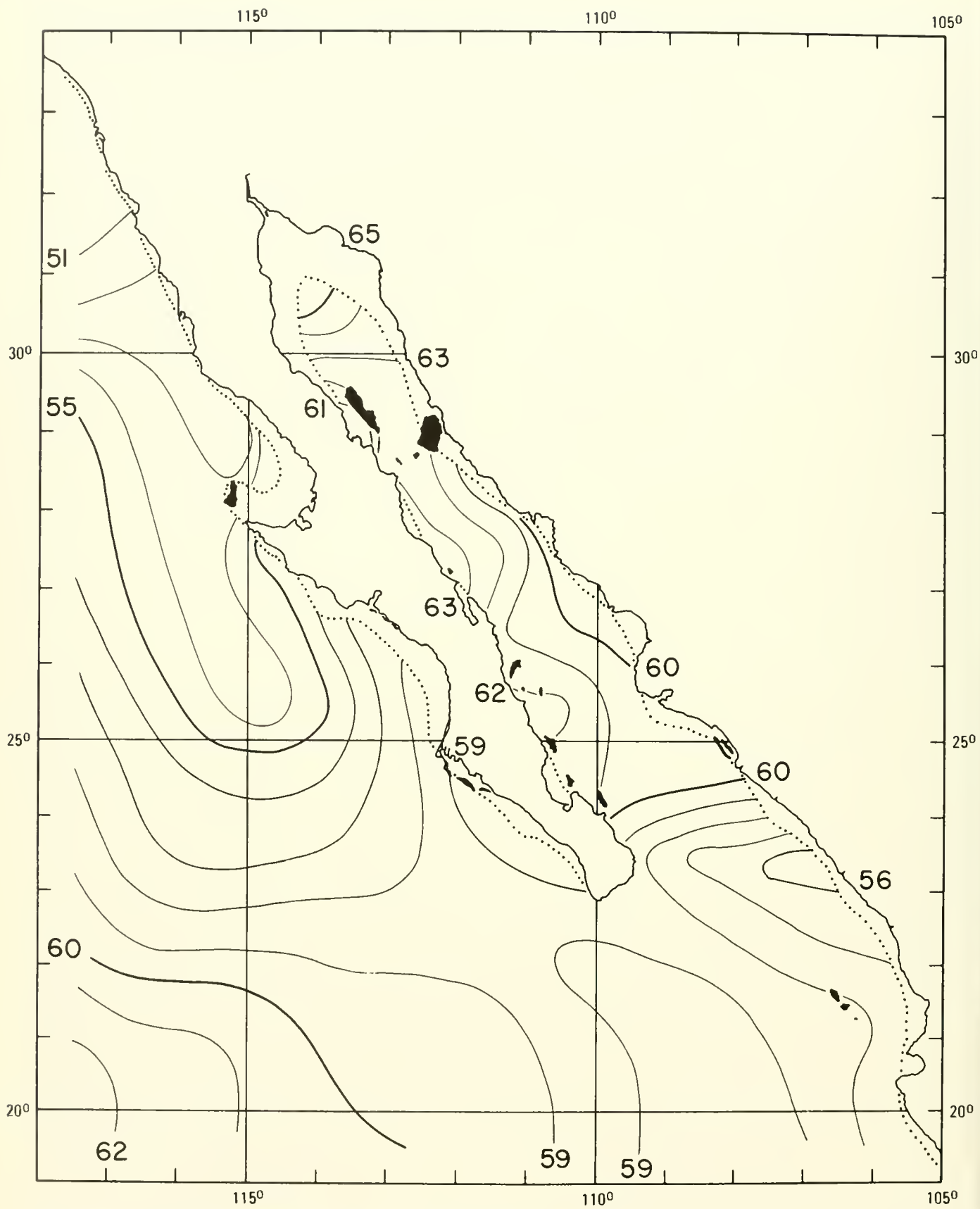


Figure 65. November mean temperatures ($^{\circ}$ F) at 300 feet.

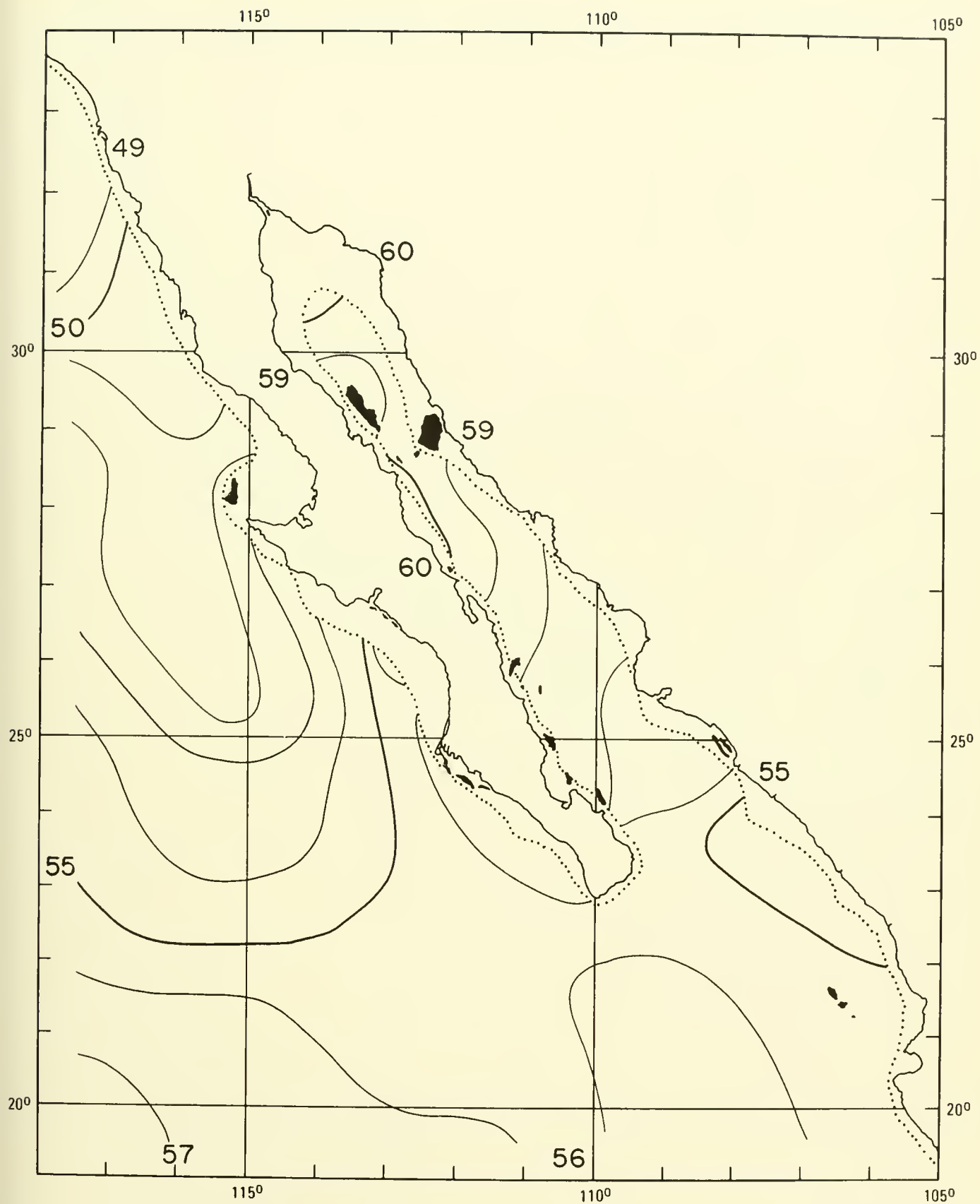


Figure 66. November mean temperatures ($^{\circ}$ F) at 400 feet.

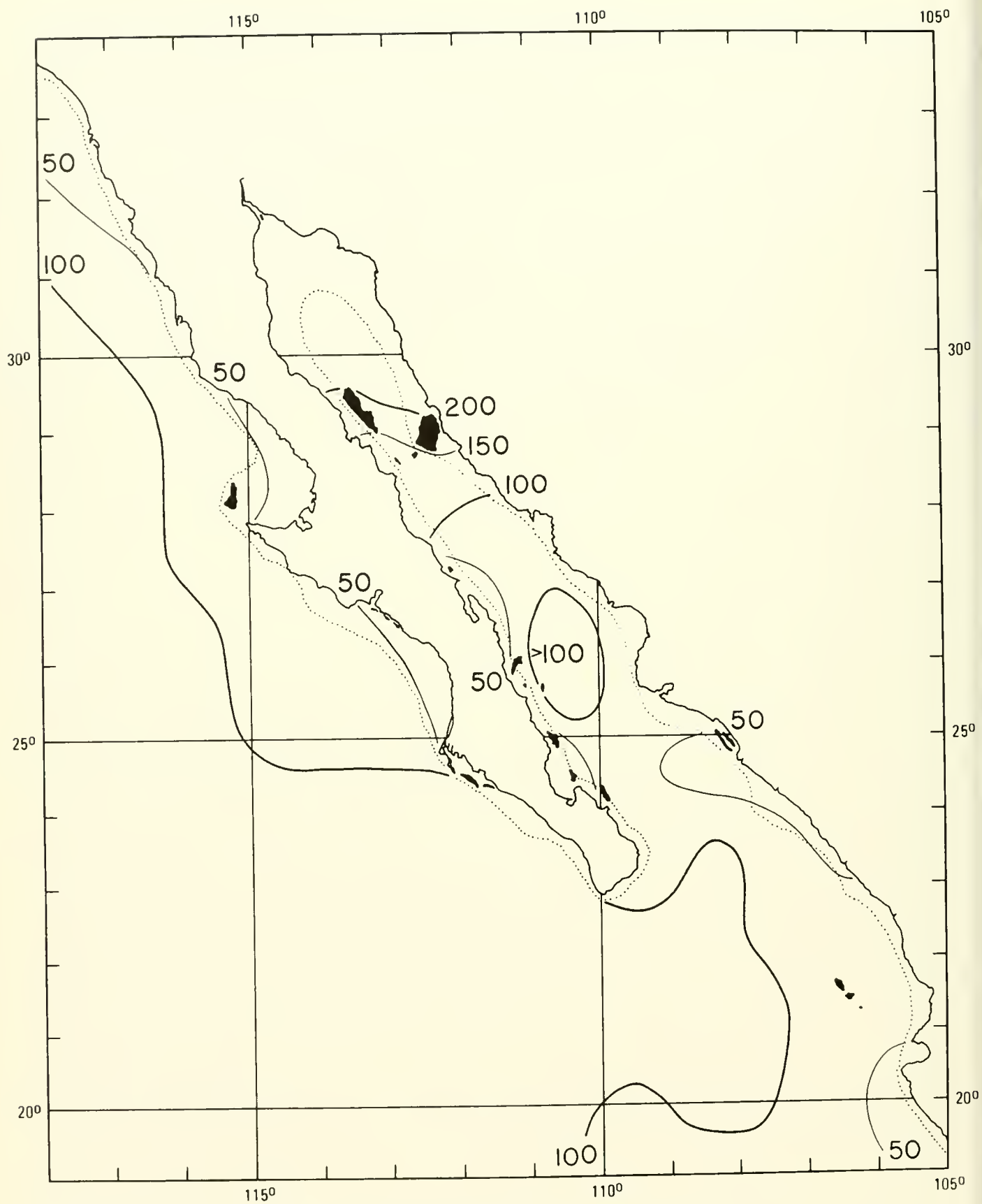


Figure 67. November mean thermocline depth (feet). (See text for definition.)

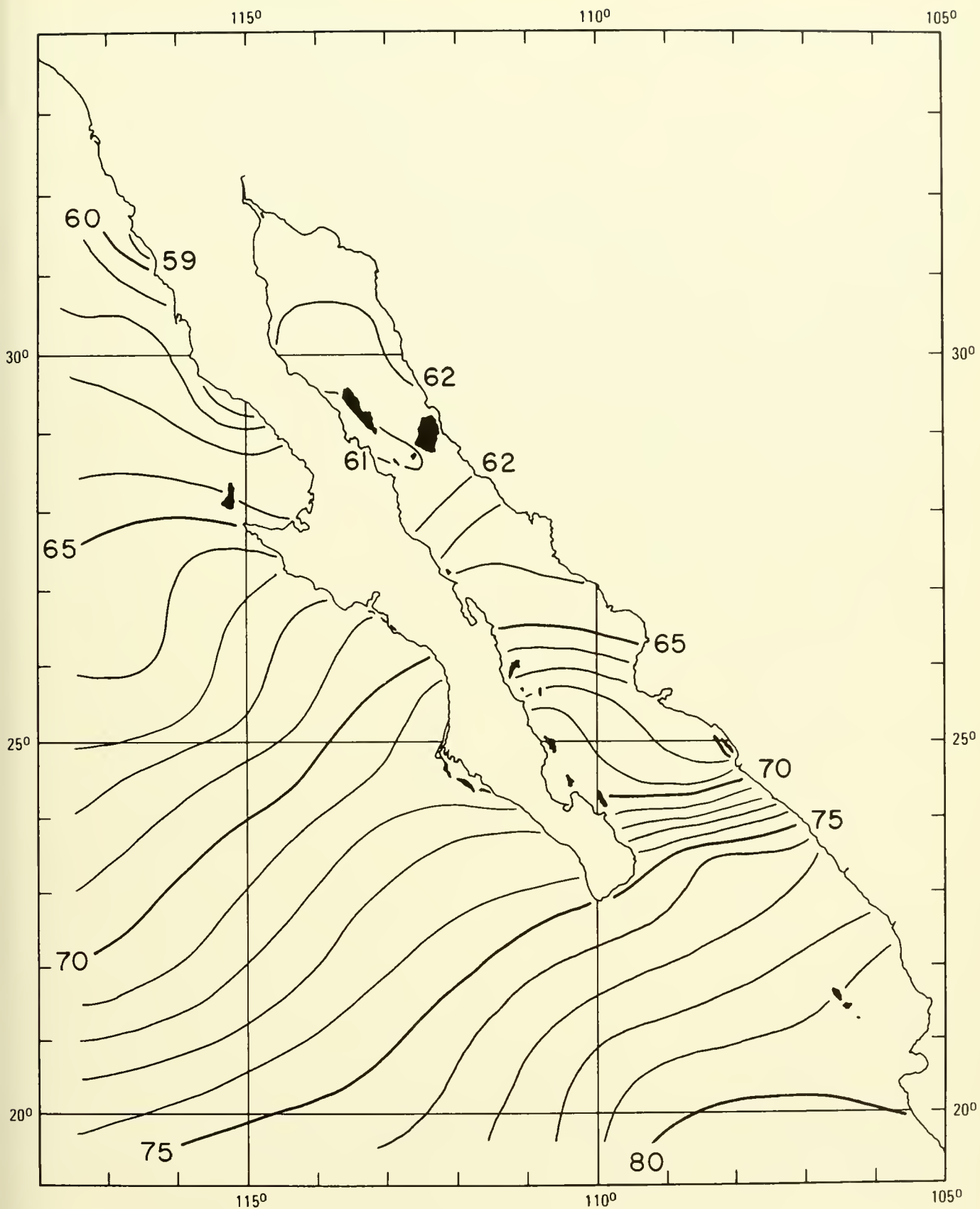


Figure 68. December mean sea surface temperatures (°F).

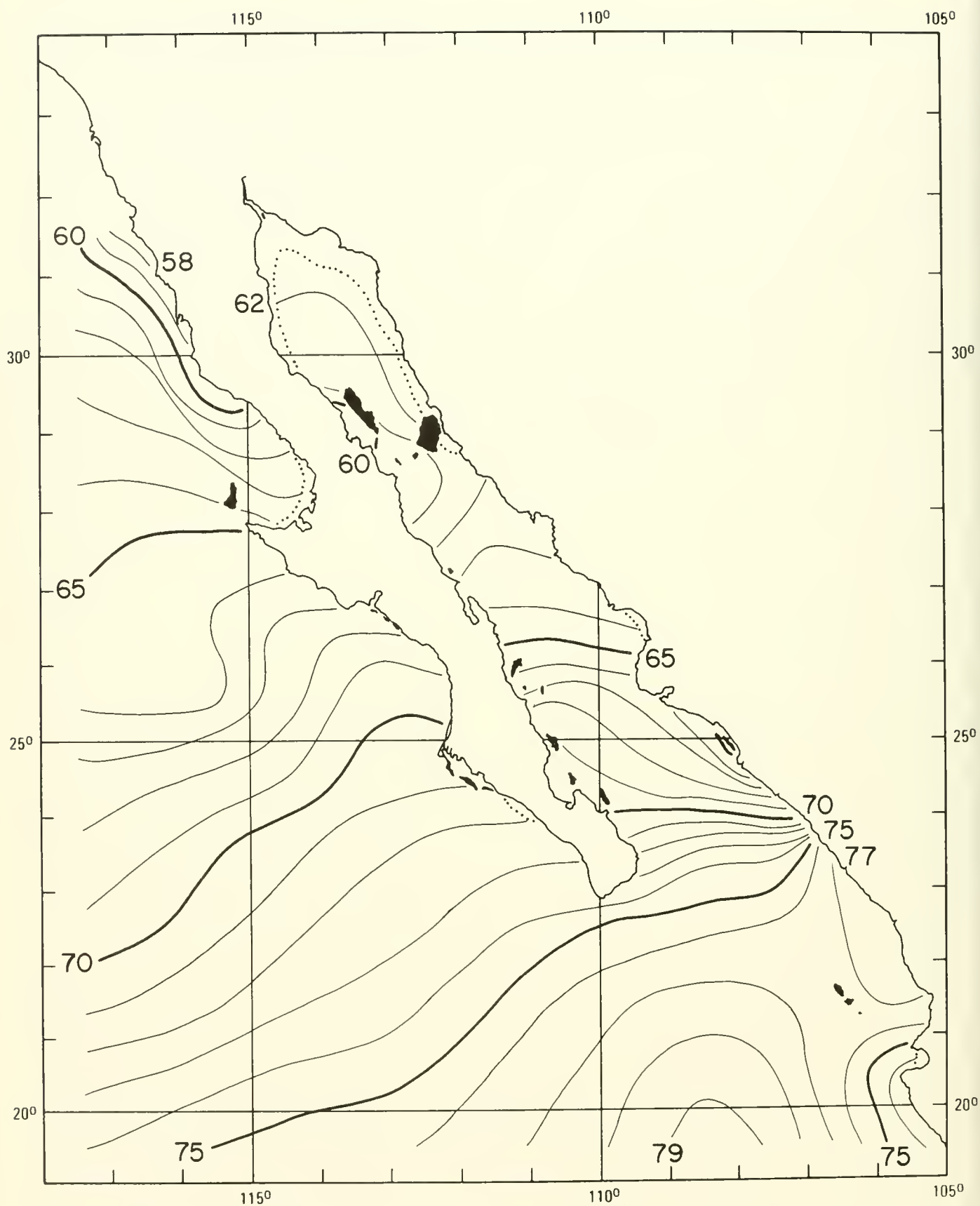


Figure 69. December mean temperatures ($^{\circ}$ F) at 100 feet.

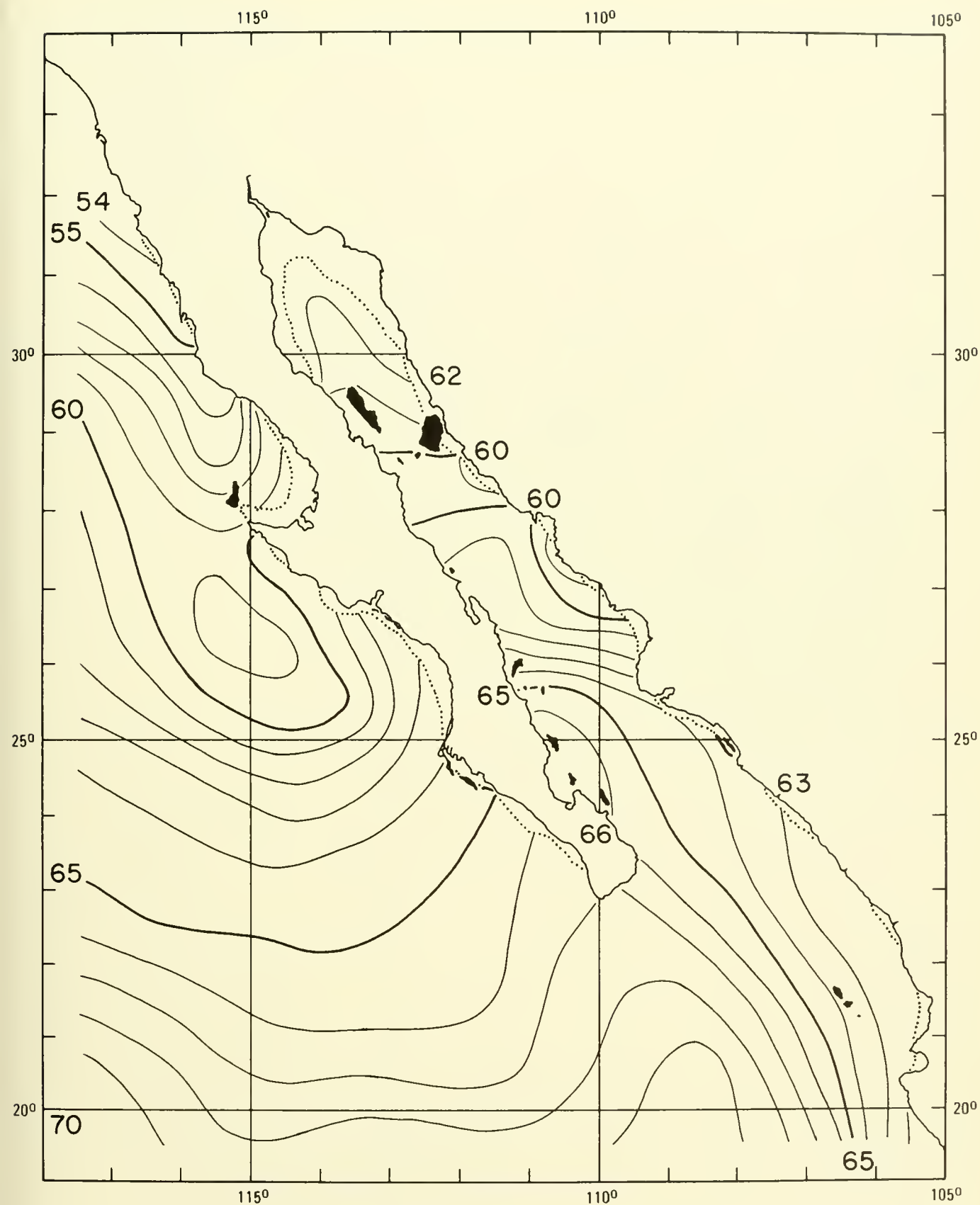


Figure 70. December mean temperatures ($^{\circ}$ F) at 200 feet.

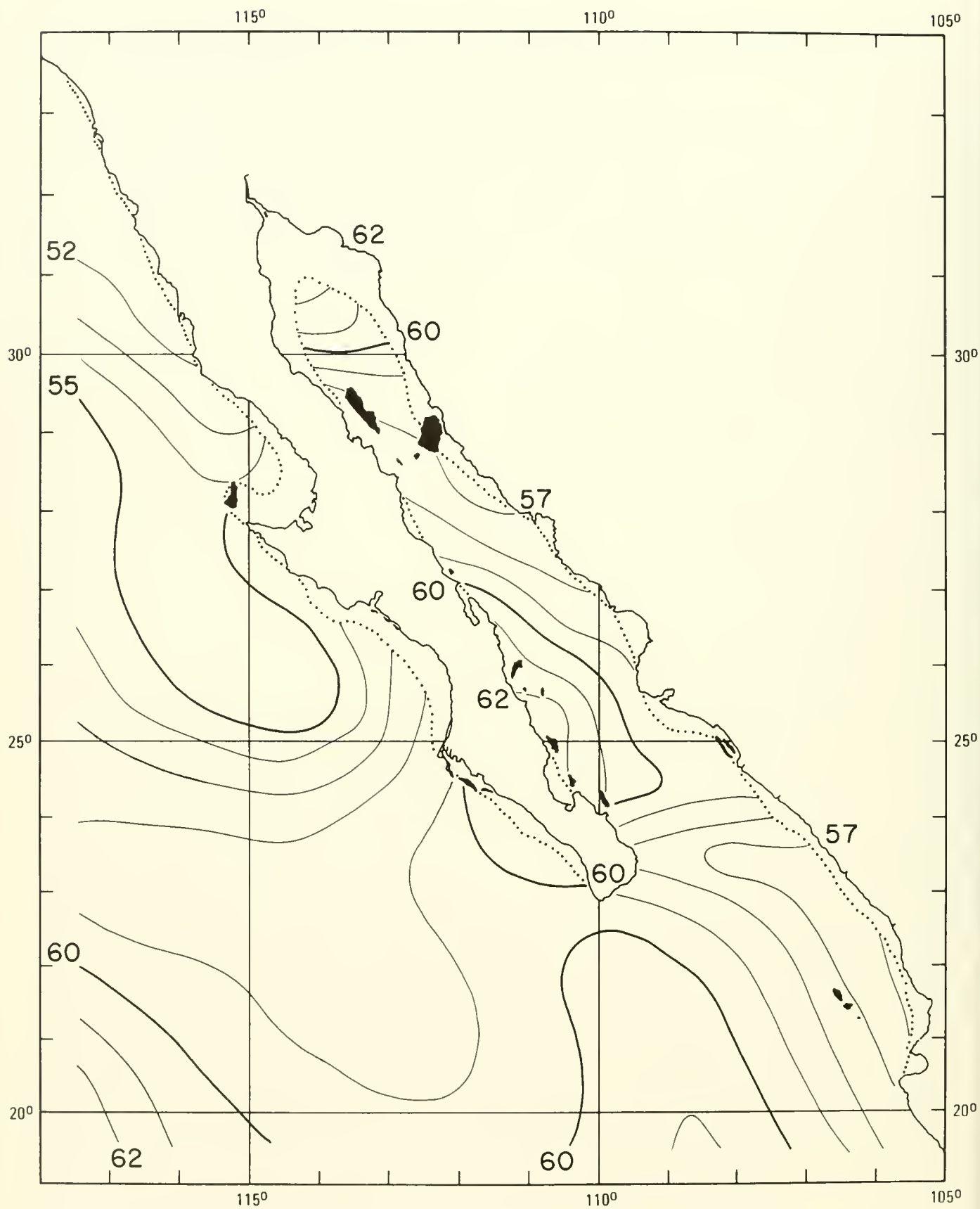


Figure 71. December mean temperatures ($^{\circ}$ F) at 300 feet.

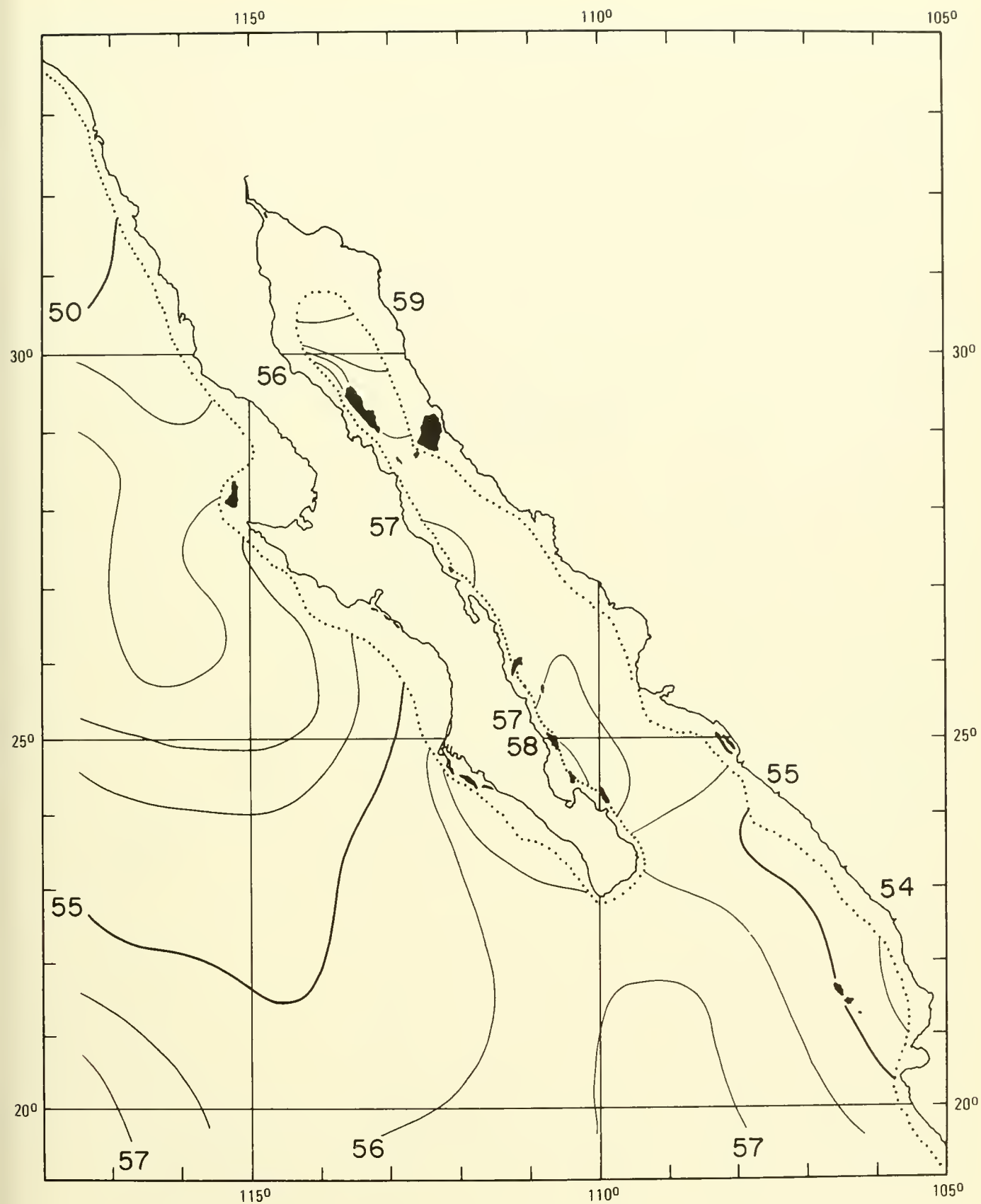


Figure 72. December mean temperatures ($^{\circ}$ F) at 400 feet.

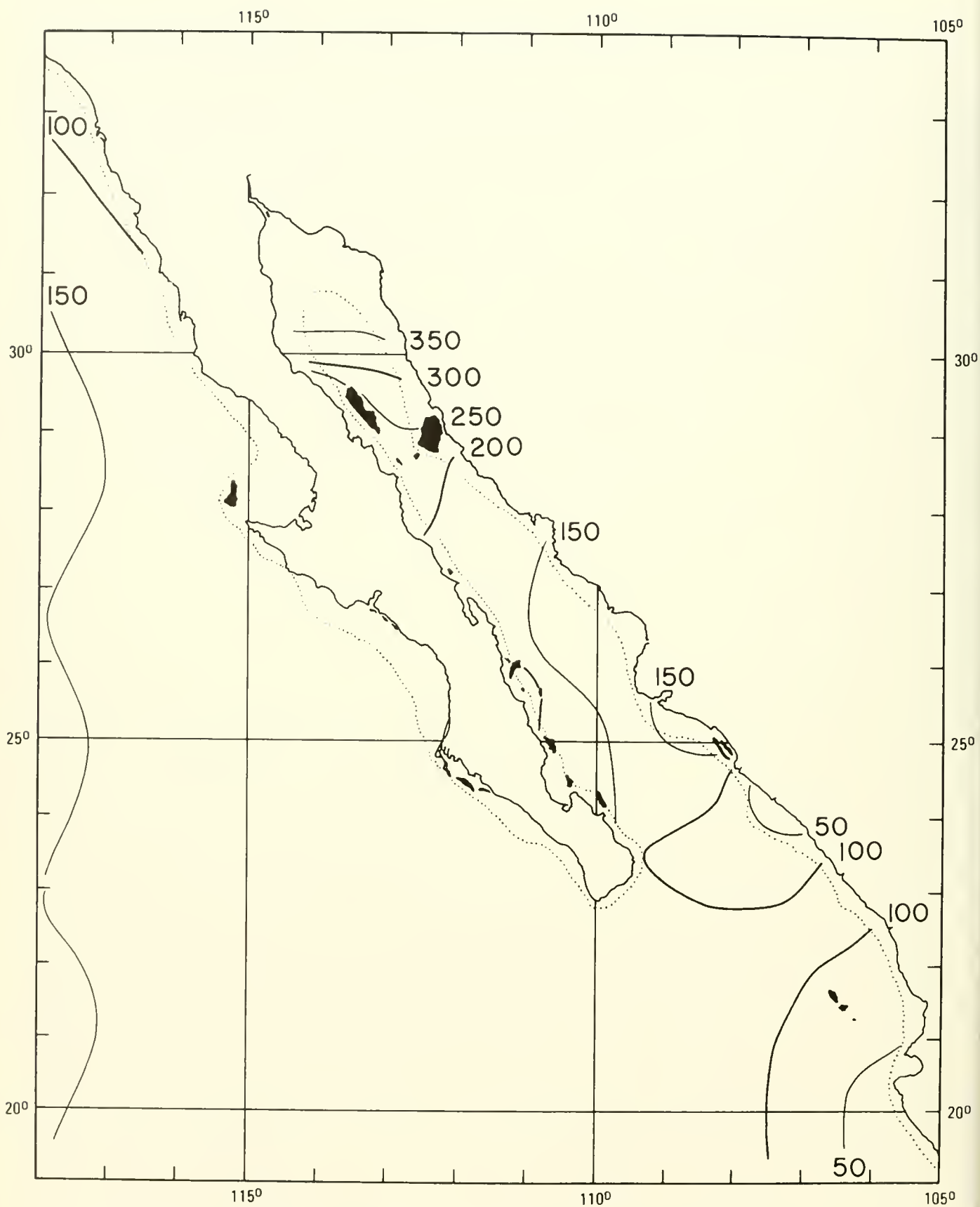
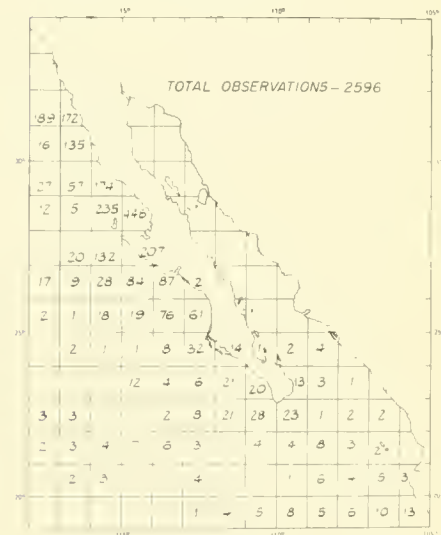
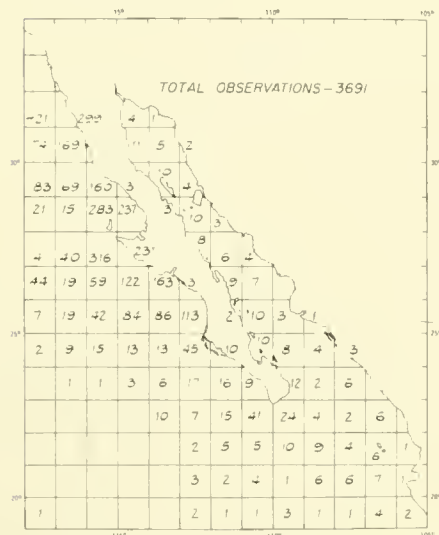
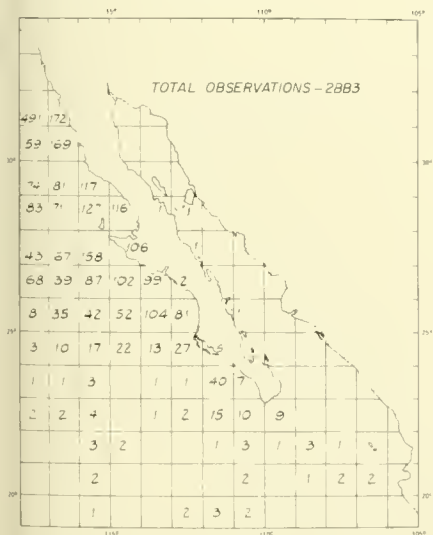
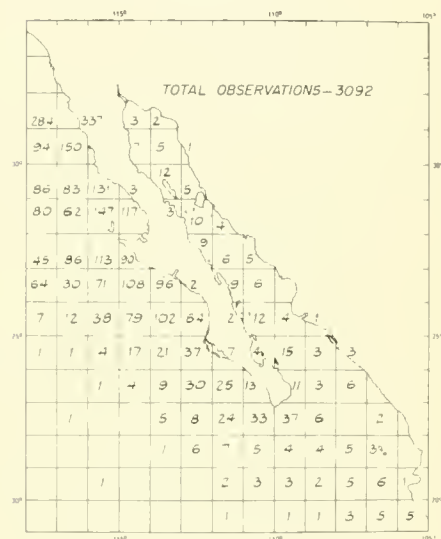
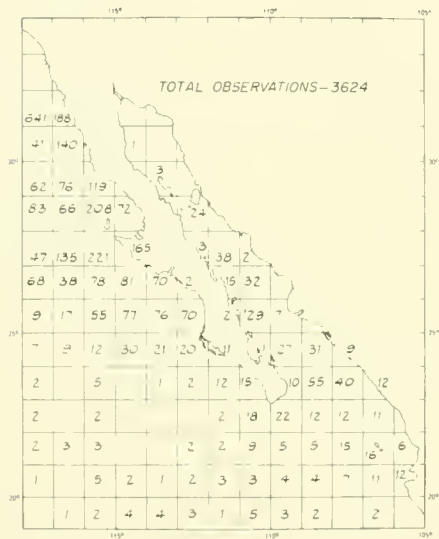
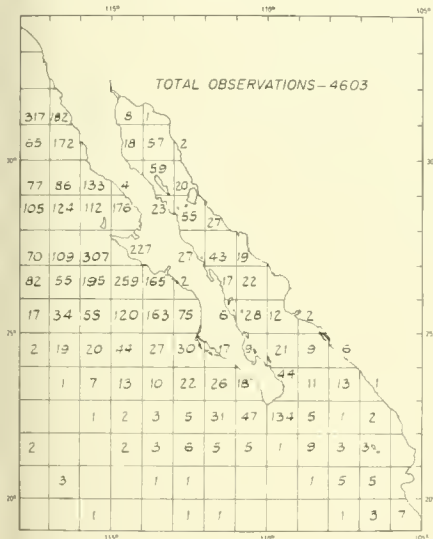
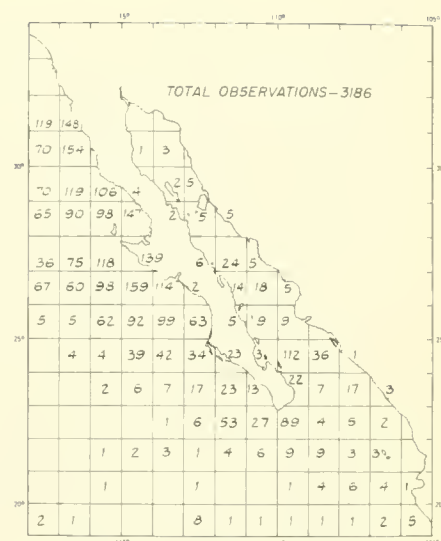
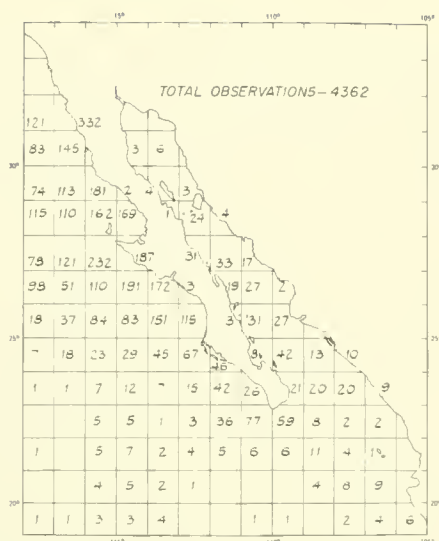
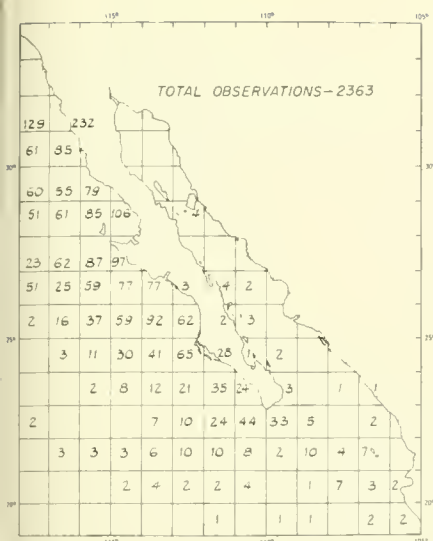


Figure 73. December mean thermocline depth (feet). (See text for definition.)



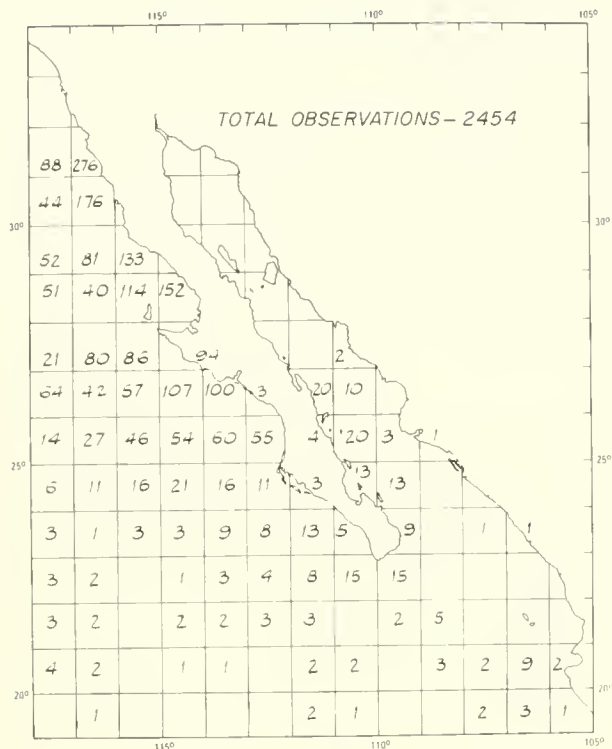


Figure 83. October numbers of observations by 1° quadrangles.

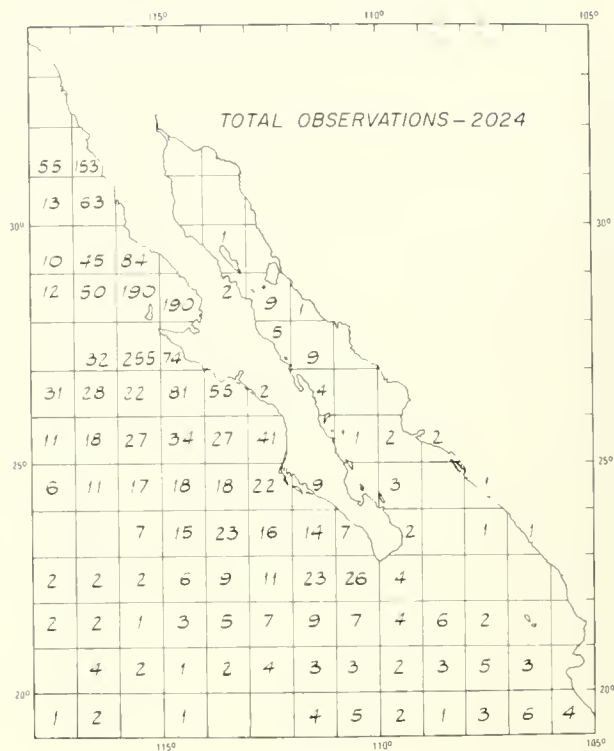


Figure 84. November numbers of observations by 1° quadrangles.

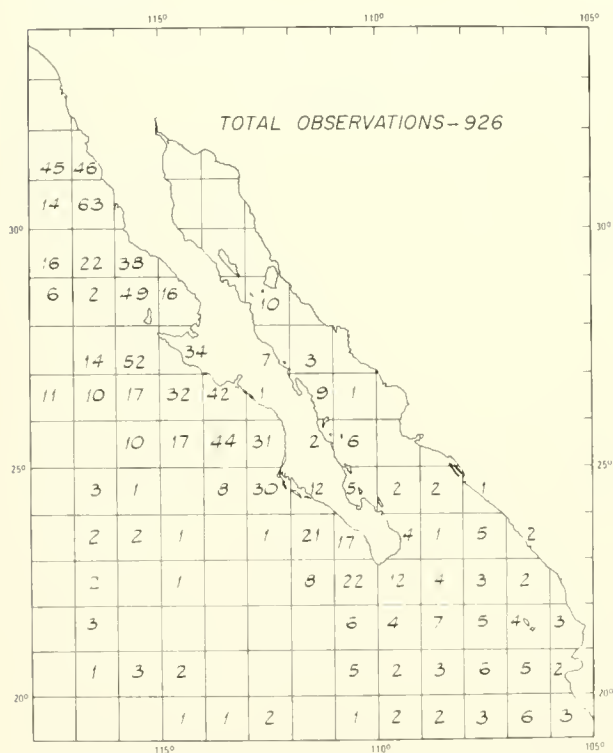


Figure 85. December numbers of observations by 1° quadrangles.

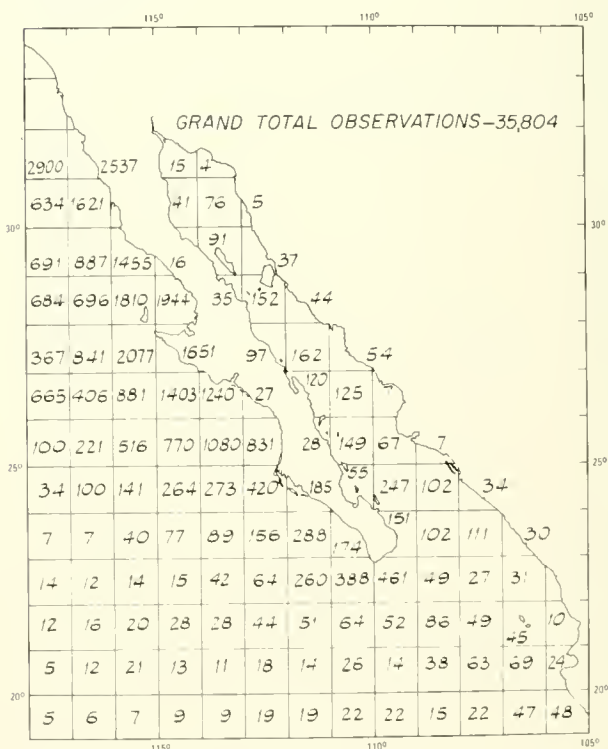


Figure 86. Numbers of observations by 1° quadrangles, total for all months.

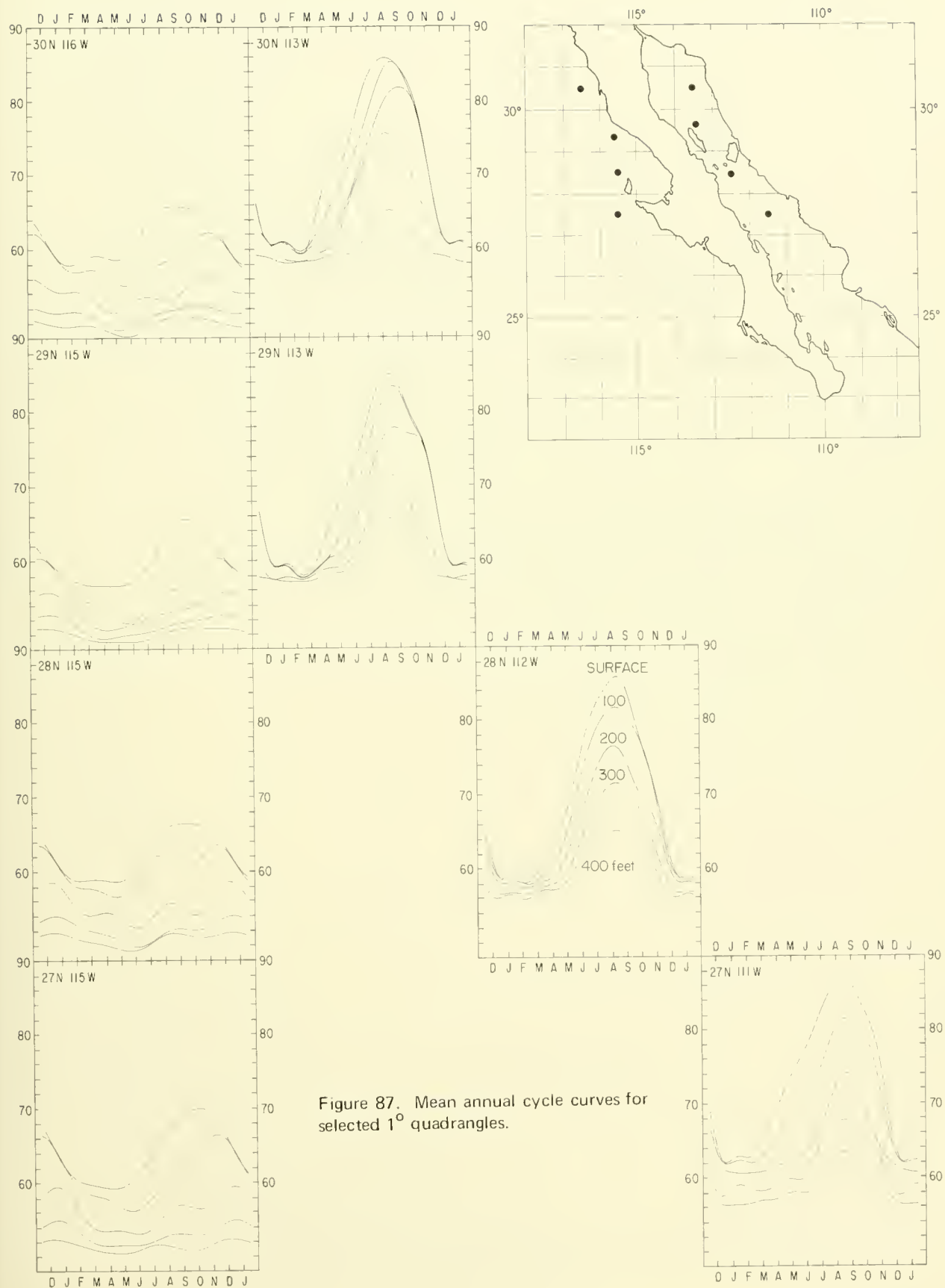


Figure 87. Mean annual cycle curves for selected 1° quadrangles.

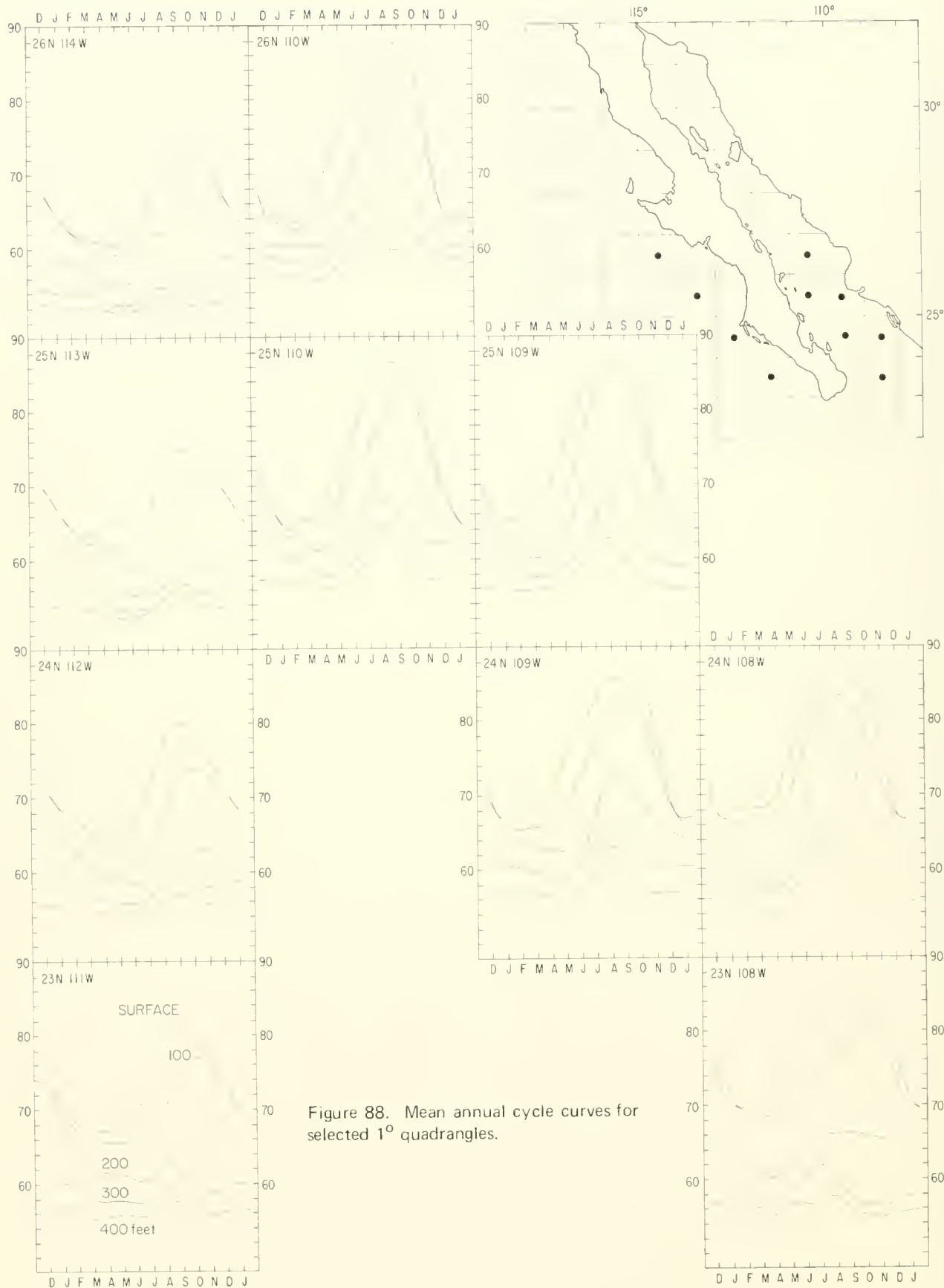


Figure 88. Mean annual cycle curves for selected 1° quadrangles.

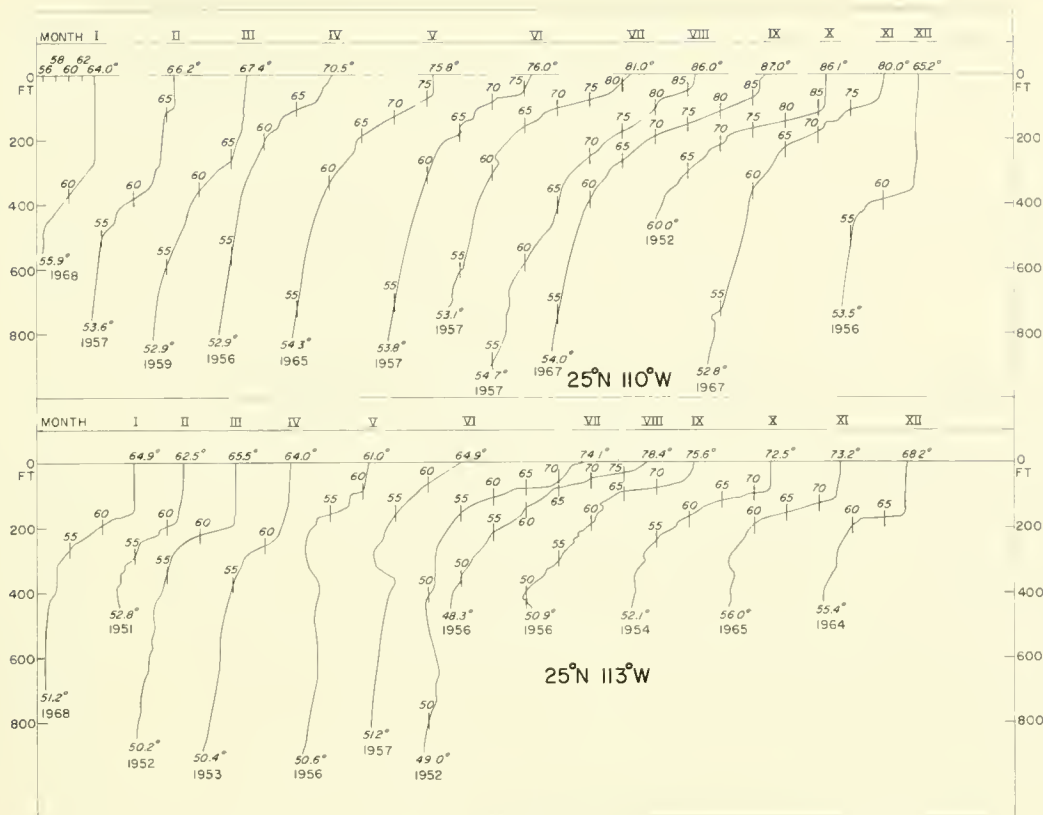


Figure 89. Selected bathythermograph traces, showing typical temperature-depth structure at corresponding latitudes along the Pacific Coast and in the Gulf of California.

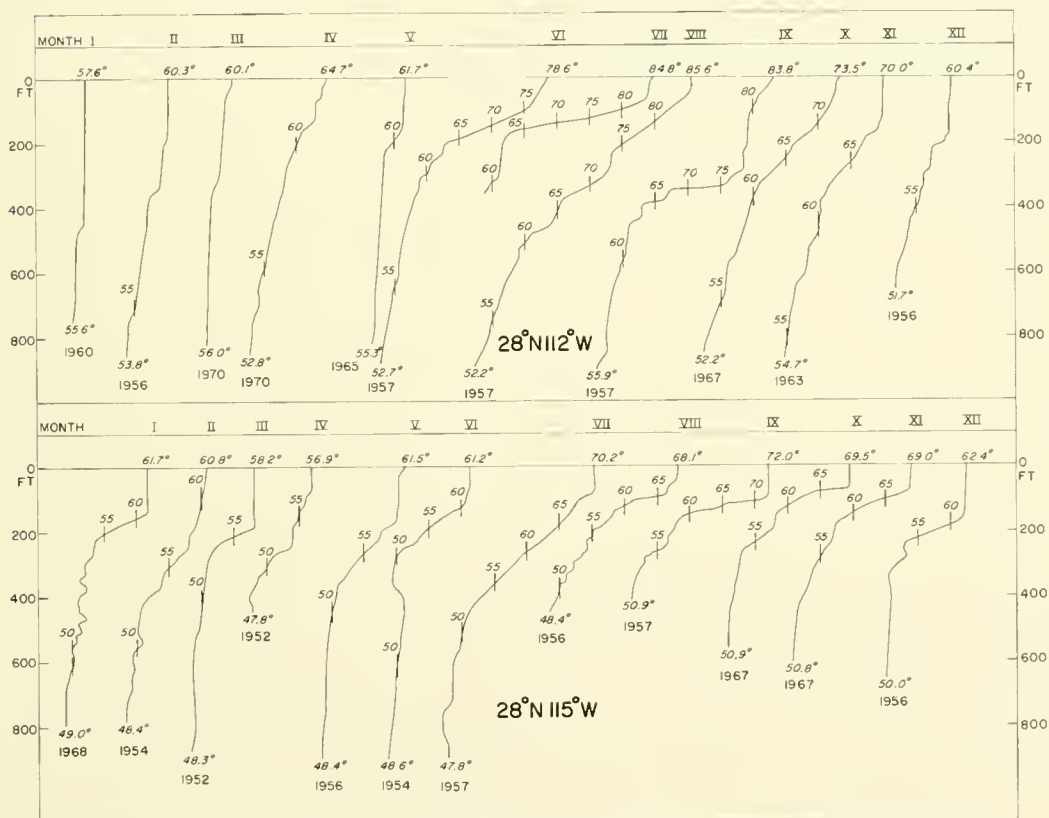
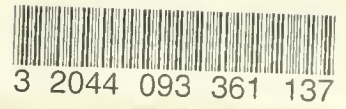


Figure 90. Selected bathythermograph traces, showing typical temperature-depth structure at corresponding latitudes along the Pacific Coast and in the Gulf of California.

BOUND SEP 1974

Date Due

~~Nov 20~~



De F.

